

# Long-term public transport accessibility in Flanders and the Brussels-Capital Region, 2016–2025

A gravity-based assessment of the Basisbereikbaarheid  
policy rollout

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## Acknowledgements

In secondary school, I studied Latin for six years and, combined with a general appetite for history, it turned me into something of a Classicist; both Romanophile and Philhellene. Although my Latin has become rusty over the years, my fascination with the ancient world has only deepened. During the process of writing this thesis, I could not help but think of other journeys... epics from a long bygone time. So naturally, I wanted to frame my thesis journey as a metaphor of an ancient Greek epic. Small problem, which one to choose? Jason and the Argonauts on their quest for the Golden Fleece? Aeneas fleeing the ruins of Troy? Xenophon's *Anabasis* and the march of his Ten Thousand? Interesting as they are, I think Odysseus' ten-year voyage back home after the Trojan war fits the narrative best. Although I have to admit I recently read Stephen Fry's *Odyssey*, so that may have influenced the choice as well.

Reflecting on my journey, it does somehow feel like I followed a path similar to Odysseus'; a long, unpredictable voyage homeward, or "thesisward" actually. At times, I found myself stranded on Kalypso's Island seemingly for an eternity, unable to make progress no matter how hard I tried. Whether it was difficulties writing, struggling to find the right direction for the thesis or getting repeatedly bogged down by R errors, many things stalled progress. On other occasions, I wandered perhaps a bit too close to the underworld and the shadows, especially when interim deadlines loomed. And sometimes I felt like getting devoured by a mountain of coding, writing and reading. Perhaps Odysseus and his companions did not feel too dissimilar when locked in the cave of the cyclops Polyphemos.

Nonetheless, Odysseus had his loyal crew beside him... though, as the story goes, they didn't exactly survive the whole voyage. I seem to have been more fortunate, my "crew" of supervisors, peers, friends, family and everyone present in the Geogang not only survived the ordeal, but kept me afloat throughout it. Their advice, encouragement, and (from time to time) good humour have been indispensable. I owe particular thanks to my supervisors: Ate Poorthuis and Céline Van Migerode, who more than once offered valuable guidance and wisdom much like Athena did time and again for Odysseus.

And so, though the trip was long and full of detours (public transport pun intended), I too have reached my Ithaka. To all who public-transported with me in one way or another: thank you, it was nice having you along.

## Contribution statement

This master's thesis was executed by Jonas Vanhoef under the supervision of Prof. Dr. Ate Poorthuis and co-supervisor Céline Van Migerode.

This study builds upon earlier work on accessibility measures and calculations. Using a place-based approach to assess accessibility change by public transport in Flanders and the Brussels-Capital Region between 2016 and 2025. To accomplish this, R scripts were built from scratch without prior existing scripts or code, using the `r5r` library to compute public transport travel times (Pereira et al., 2021). The overall methodology and scripts were developed by Jonas Vanhoef, but Gen AI tools were used for debugging and code testing (OpenAI, 2025).

## Summary

This thesis examines how easy it is to reach everyday destinations by public transport in Flanders and the Brussels-Capital Region and how this accessibility has changed over the past decade. In recent years, the public transport network has been reshaped under the *Basisbereikbaarheid* reform, rolled out in phases between 2022 and 2025. Against that backdrop, the study asks two questions. First: how, and to what extent, did accessibility evolve between 2016 and 2025, both during each reform phase and over the whole period, and do patterns differ between dense and less-dense areas? Second: Which concrete changes to the network: service frequency, route configuration, stop locations, and timetables drove the observed shifts?

To answer these questions, the analysis uses a gravity-based accessibility measure that counts all reachable opportunities while giving more weight to closer, faster trips. Two destination types stand in for different travel scales: secondary schools represent local access, and museums represent regional access. Accessibility is computed for four snapshots: 2016, 2023, 2024 and 2025, based on GTFS timetable data and on OSM road network data. Typical time windows are used (school arrivals and dismissal for the school analysis, morning and evening, weekdays and weekends for museums). Results are mapped at the hexagon level across the entire study area and explored in depth through two case studies: Morkhoven (rural, reliant on a single bus axis) and Pelt (semi-rural node with several frequent lines).

The 2016 baseline shows the highest accessibility in and around the Metropolitan Core Area and along the main inter-urban corridors. Outside these corridors, accessibility is patchier, with clear border effects where cross-border destinations are not counted. In general, densely populated places score higher, but many smaller towns also perform well when well served by rail or frequent bus lines. Across 2016–2023, the picture diverges by scale. Regional accessibility (to museums) improves in most places, while local accessibility (to schools) edges down. By the *Basisbereikbaarheid* phase 2 in January 2024, media coverage focused on the removal of a large number of stops, yet the measured effect between 2023 and 2024 is modest: on average, accessibility remains stable or even rises slightly, although results vary locally, and rural areas show more volatility than cities. The following year tells a different story. Between 2024 and 2025, coinciding with phase 3 and several network adjustments, accessibility falls sharply for a large majority of residents, with regional access dropping more than local access. In short, small earlier gains were largely offset by more

recent declines, leaving a mixed decade-long balance: local access tends to end lower than in 2016, while regional access retains some of its earlier gains but loses ground in 2025.

The case studies explain the mechanics behind these maps. In Morkhoven, improvements linked to higher frequency on the central corridor were fragile; roadworks and rerouting in 2025 lengthened walks to stops and erased those gains. This underlines how vulnerable single-axis rural networks are to small disruptions. Pelt, by contrast, is more resilient because multiple frequent lines share the load, yet the removal of a seemingly minor northern line still reduced access for nearby residents, evidence that small lines can have outsized importance where alternatives are thin. Time-of-day profiles reinforce this difference: Morkhoven's accessibility fluctuates more across the day, reflecting dependence on a single corridor and longer waits if a bus is missed; Pelt's curves are flatter, with more alternatives smoothing the peaks and troughs.

Who benefited and who did not also varies by place. Over the decade, rural western Flanders and central Limburg often gained, while the metropolitan core and its fringes often lost accessibility. On average, lower-density places are not uniformly worse off, but they clearly show more variability: small timetable changes, a stop removal or the loss of a minor line can swing accessibility sharply up or down.

These findings carry straightforward policy lessons. Modest, well-targeted frequency increases can deliver meaningful benefits in rural contexts. Large restructuring that prioritises trunk corridors but removes small routes or many stops risks cutting off people who rely on them unless there is a clear substitute nearby. The results also suggest that more research should be done regarding mobility-impaired users, as they might be disproportionately affected by the removal of many bus stops.

The study is intentionally conservative in how it measures change. It uses scheduled service rather than day-of-operation conditions, so the effects of delays, cancellations or strikes are not captured. The pedestrian network is held constant across years to make fair comparisons of public-transport changes, which means local walking conditions may in reality have changed in some places. Population and destination layers are treated as stable for the same reason, so land-use change is not a driver of results. Like all regional accessibility work, the analysis is also subject to border effects and to the way space and time are aggregated. These choices trade realism for comparability and help isolate the effect of the transport network itself. Overall, the thesis shows where access improved, where it declined, and why.

## List of abbreviations

|           |                                                                                                                                                                           |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| HA        | Home–Amenity (pairs/matrix/locations)                                                                                                                                     |
| BCR       | Brussels-Capital Region                                                                                                                                                   |
| GTFS      | General Transit Feed Specification                                                                                                                                        |
| MAUP      | Modifiable Areal Unit Problem                                                                                                                                             |
| MCA       | (Flemish) Metropolitan Core Area                                                                                                                                          |
| MIVB/STIB | Brussels Intercommunal Transport Company<br>Dutch: “Maatschappij voor Intercommunaal Vervoer te Brussels”<br>French: “Société des Transports Intercommunaux de Bruxelles” |
| MTUP      | Modifiable Temporal Unit Problem                                                                                                                                          |
| NMBS/SNCB | National Railway Company of Belgium<br>Dutch: “Nationale Maatschappij der Belgische spoorwegen”<br>French: “Société Nationale des Chemin de fer Belges”                   |
| OD        | Origin–Destination (pairs/matrix/locations)                                                                                                                               |
| OSM       | OpenStreetMap                                                                                                                                                             |
| OVG       | Onderzoek Verplaatsingsgedrag (Flanders Travel Behaviour Survey)                                                                                                          |
| POI/POIs  | Point(s) of Interest                                                                                                                                                      |
| TEC       | Walloon public transport operator, “Transport En Commune”<br>Or since 2019: Opérateur de Transport de Wallonie (OTW)                                                      |

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# 1 Introduction: The trip ahead

Over the past decade, public transport research has attracted increased attention in both academic literature and policy debate due to its myriad of social benefits, ranging from increased quality of life to enhanced sustainability. (Banister, 2011; Saif et al., 2019). Realising these benefits requires a well-functioning public transport network, which in turn depends on cooperation and planning between stakeholders, and continuous governmental funding (Hensher et al., 2015; Sohail et al., 2006). In Flanders, however, the amount of funding that should be allocated to public transportation remains up for debate (Vlaams Parlement, 2025).

Confronted with limited resources and embracing a new vision on mobility, the Flemish government transitioned from a supply-driven to a demand-driven public transport model. It emphasises multimodal travel, tailored services, and closer collaboration with local authorities (Vlaamse Overheid, 2025). The 2019 *Basisbereikbaarheid* (basic accessibility) decree was introduced to formalise this shift, after which Flemish bus provider De Lijn significantly restructured its bus services (Rekenhof, 2024; Vlaamse Overheid, 2025). These changes reignited the public transport debate, sparking intense backlash against their extent and impact (VRT NWS, 2024a, 2024b, 2024c). Apart from efficiency, the new decree aims to make “schools, hospitals, business parks, and sports, cultural and shopping centres fluently accessible for everyone” (Vlaamse Overheid, 2025). However, the lack of a clear definition and the absence of measurable benchmarks make evaluation difficult. Combined with a sweeping network overhaul, it underscores the need to examine how accessibility evolved during the implementation of the new policy.

Therefore, this study aims to examine the impact of the public transport changes in Flanders and the Brussels-Capital Region (BCR) based on two main research questions. Firstly, *how and to what extent did local accessibility to secondary schools and regional accessibility to museums evolve across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025? How do these trajectories differ between high- and low-density areas?* Investigating this research question allows us to get a better understanding of where and to what extent accessibility changed and how those changes differ between urban and rural areas.

Secondly, *how have changes in service frequency, route configurations, stop locations and timetables across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025 driven the observed shifts in public transport accessibility?* This research question focuses on the link between transit service alterations

and how exactly they impact accessibility. Combining the insights of these research questions addresses key gaps in the scientific literature. It dives deeper into long-term phase-by-phase accessibility assessment at a large geographical scale, and it tries to unpack how different factors influence accessibility. Additionally, the resulting analyses may also offer transit planners and policymakers an empirical overview of how their service adjustments impacted public transport accessibility in Flanders and the BCR.

The following paragraph gives a roadmap for navigating this thesis. First, I provide an overview of the state-of-the-art to illustrate the relevance of public transit and define the concept of accessibility, along with an overview of different measures. In the subsequent section, the methodology is described in detail. The operationalisation of the chosen accessibility measure will be explained, and how it fits into the calculation procedure of the research. Additionally, this section includes how the resulting accessibility values and data will be used to answer the research questions. In the results and discussion section, an overview of the results is provided per research question, which are also compared and discussed. Thereafter, the general findings of the results are discussed alongside the limitations and the avenues for future research. The final section comprises a conclusion on the results and research.

## 2 Literature review: Overview of the routes

Public transport offers ample benefits for its users and society, making it a key focus in efforts to improve sustainability and social equity (Banister, 2011; Saif et al., 2019). Most notably, it provides an affordable alternative to private vehicle ownership as no purchasing, insurance, fuel or maintenance costs are required. Relying on public transport can alleviate traffic congestion as it reduces the number of cars on the roads, improving traffic flow (Banister, 2011; Benenson et al., 2011). In addition, public transportation generates fewer greenhouse gas emissions per capita, contributing to climate change mitigation (Basagaña et al., 2018). Health benefits can also emerge if people elect to use active travel to transit stops, such as walking or cycling, which can complement daily physical activity (Besser & Dannenberg, 2005). Lastly, public transportation facilitates access to essential amenities for people who cannot or choose not to drive (Johnson et al., 2017; Saif et al., 2019), strengthening social interaction and community connections, and reducing social exclusion in the process (Fransen et al., 2015; Saif et al., 2019).

Realising these benefits requires the development of a well-functioning public transport network, which involves addressing multiple challenges. Financial constraints are the first major impediment, as governments must consistently allocate sufficient funds to develop and maintain the system (Hensher et al., 2015). Secondly, efficient public transit requires proper coordination and planning among diverse stakeholders, including service providers, planners and governmental institutions. These actors must attempt to integrate various modes of transportation while also accounting for factors as population density, demand and land-use (Sohail et al., 2006). When established, the ideal system should ensure equitable access and affordability, essential for addressing socioeconomic disparities. This implies that low-income neighbourhoods and rural areas must also be served by affordable and sufficient public transit. Failure to do so may result in transport poverty and injustice for marginalised communities (Delbosc & Currie, 2011; Gössling, 2016).

Public transit accessibility can clearly provide a wide range of benefits. However, to evaluate, improve and plan for these benefits, it is vital to understand what accessibility entails. This includes clarifying the concept itself, identifying its key components and reviewing the measures and methods used to assess it. A clear conceptualisation of accessibility is necessary to examine the performance of public transport systems and to comprehend their capacity to obtain the benefits associated with it.

## 2.1 Defining (public transit) accessibility

The concept of accessibility emerged in the 1950s and was initially defined as the ease of reaching a desired destination (Hansen, 1959). It has since become widely used in fields such as transport and urban studies, geography, and economics and has consequently been operationalised in various ways (Geurs & van Wee, 2004; Stępnik et al., 2019). Inherent to the concept of accessibility is its broad scope, as it encompasses several interrelated components. To disentangle this complexity, Geurs & van Wee (2004) and Levine et al. (2019) subdivided the concept into four important theoretical aspects, each comprising a set of key factors. (Handy & Niemeier, 1997; Litman, 2017; Siddiq & Taylor, 2021).

- The *land-use component* refers to spatial distribution, quality and quantity of destinations (shops, schools, jobs, etc.) as well as the demand for these amenities in residential areas. It also includes competition for opportunities that arise from the confrontation of its supply and demand (e.g., competition for jobs).
- The *transportation component* encompasses the characteristics of all transit systems (in this case: public transport or walking). More specifically, it includes travel times, costs, external factors (such as crowdedness, (un)comfortability, delays, strikes, safety and accidents) and infrastructure-related factors such as travel speed, public transport schedules, routes and stops.
- The *temporal component* relates to temporal constraints, which include the time available for individuals to take part in activities (such as work, recreation and education) and the availability of opportunities and public transportation systems at different times of the day.
- The *individual component* describes demographics (such as income, age, educational level and gender), people's abilities (e.g., a person's physical condition or perceptions) and opportunities (travel budget, education level, etc.). These characteristics can strongly influence people's accessibility to opportunities.

This study adopts a slightly modified version of the accessibility definition proposed by Geurs and van Wee (2004) to emphasise public transport. *Public transit accessibility refers to the theoretical and potential extent to which land-use and public transport systems enable (groups of) individuals to reach destinations by means of a (combination of) public transport mode(s) or walking.* In other words, it reflects how easy a set of destinations can be reached by public transit or walking. In the definition, '*theoretical*' implies the focus lies on scheduled trips, thereby excluding external factors as delays, strikes, (un)comfortability, availability of space and so on. '*Potential*' indicates that all amenities reached will contribute to the level of accessibility, thus excluding diminishing marginal utility. This definition, alongside the research questions, already indicates several important criteria for selecting an appropriate accessibility measure.

## 2.2 Measuring accessibility

Selecting an appropriate accessibility measure? Is there no universally accepted measure then? No, the diversity of definitions, the wide array of components and different disciplinary paradigms have led to the development of numerous accessibility measures (Geurs & van Wee, 2004; Siddiq & Taylor, 2021; van Wee, 2016). This is unsurprising, as accessibility measures are often tailored to the specific objectives of individual studies. The angle from which these objectives are approached depends on a researcher's disciplinary background, their assumptions and priorities (Geurs & van Wee, 2004; Stępnia et al., 2019). Similarly, I propose a definition that aligns with this study's objectives and thus needs a corresponding measure.

Before examining the main types of accessibility metrics, it is important to reflect on what an 'ideal' metric should entail. Beyond including the theoretical components discussed earlier, an ideal measure should include the following three aspects. Firstly, it should function as a socioeconomic indicator by allowing social and economic impact assessments. Secondly, the measure should be straightforward to operationalise and practical to use. Lastly, it should be easy to understand, communicate and interpret by both scientists, planners and policy makers (Geurs & van Wee, 2004). In theory, a measure seamlessly integrating all these aspects could be used universally for all accessibility calculations. In practice, however, most measures only focus on a specific set of aspects depending on the adopted perspective. The four main accessibility measure perspectives are: infrastructure-based, utility-based, people-based and place-based measures (Geurs & van Wee, 2004; Siddiq & Taylor, 2021).

### Accessibility measure overview

*Infrastructure-based measures* analyse the performance of the transport system by focusing on parameters as congestion levels or operating speeds of the road network. While these measures score highly in terms of operationalisation, communicability and low data requirements, they lack theoretical depth, particularly in accounting for individual characteristics and temporal constraints (Geurs & van Wee, 2004). Secondly, *utility-based measures* evaluate the benefits arising from people's access to opportunities. In contradiction to infrastructure-based metrics, they are well-suited for economic evaluations of user benefits and satisfy all the theoretical criteria, except for the temporal component. While these measures are foundationally stronger, they come at the cost of reduced communicability and interpretability, especially for laypersons such as policy makers (Geurs & van Wee, 2004; Koenig, 1980; Páez et al., 2012). *People-based measures*, rooted in Hägerstrand's (1970) space-time geography, analyse accessibility from the perspective of

households or individuals, taking into account temporal constraints and personal preferences. It refers to the things a person can do at a certain time of the day. Unsurprisingly, their strengths are the theoretical criteria, especially in terms of the assessment of individual variations in accessibility (Geurs & van Wee, 2004; Kwan, 1998). However, given the need for detailed information on individuals' time budgets, this approach can be computationally intensive and data-demanding. The data required to construct these time budgets is also rarely available and difficult to aggregate, limiting the applicability of people-based approaches for research at larger spatial scales (Geurs & van Wee, 2004; Pereira & Herszenhut, 2023; Siddiq & Taylor, 2021). In contrast, *place-based measures* typically assess the level of accessibility from specific origin locations to various amenities and activities. For example, they may evaluate the number of hospitals within 20 minutes of the origin location. There is a wide variety of place-based measures, each with its own distinct benefits and limitations; the three most common ones are discussed below (Geurs & van Wee, 2004; Horner & Downs, 2014; Siddiq & Taylor, 2021).

#### Place-based measures

Within the place-based perspective, distance, contour and gravity measures offer different ways to operationalise accessibility (Fig. 1). The crudest type is *distance measures*, which compute either the Euclidean distance or the road network distance between an origin and (the nearest) destination, expressed as physical distance or travel time (Geurs & van Wee, 2004; Yenisetty & Bahadure, 2020). The limited data requirements mean that they are easy to operate and communicate, but at the cost of failing to incorporate key theoretical components such as temporal constraints and individuals' characteristics (Geurs & van Wee, 2004).

*Contour measures* are more advanced as they account for multiple destinations compared to only one destination for distance measures. They sum the number of opportunities within a given distance, travel time, or monetary cost, whereby opportunities in the same bracket (e.g. within 10 minutes) are typically weighted equally (Geurs & van Wee, 2004; Siddiq & Taylor, 2021; Wachs & Kumagai, 1973). For instance, contour measures allow for comparing the total number of opportunities reached within a 10 -and 20-minute travel time window. Even though these measures are relatively comprehensive, easy to apply, and undemanding in terms of data, they fail to evaluate the combined effect of the transport and land-use. To illustrate, within a 20-minute window, an opportunity located 1 minute away counts the same as an opportunity located 19 minutes away. On top of that, they do not include individuals' characteristics and rely on arbitrary cutoff points (Geurs & van Wee, 2004; Levinson & King, 2020).

*Gravity/potential measures* are widely used in transportation planning and accessibility assessments. They use impedance functions to provide a solution to equally weighing opportunities. Impedance functions reflect travel patterns, spatial interaction and general human behaviour by assigning higher weights to easier-to-reach destinations. Similar to Tobler's first law of geography (1970) It describes the reduction in interaction between an origin and destination as the travel costs (i.e. time, distance, monetary costs) increase (Iacono et al., 2008; Martínez & Viegas, 2013). Consequently, gravity measures can capture the combined land-use and transportation effects, while also partly accounting for individuals' preferences. They can also be applied for socioeconomic evaluations and are relatively straightforward to compute using existing data (Geurs & van Wee, 2004; Levine et al., 2019; Siddiq & Taylor, 2021). However, since impedance functions only reflect general human behaviour, other aspects such as people's actual behaviour and perception are not accounted for in gravity metrics. Additionally, the use of impedance functions complicates the measure's comprehensibility and communicability compared to distance or contour measures (Geurs & van Wee, 2004; Handy & Niemeier, 1997).

So, which perspective should be adopted in this research and why? Based on the research questions and how accessibility is defined, the selected measure used must allow for estimating both past and present accessibility, must be easily applicable at the spatial scale of Flanders and the BCR, and must be sensitive to even small changes in public transit services. Infrastructure -and utility-based measures are only partly able to estimate the access potential to opportunities via public transport. For infrastructure measures, the lack of theoretical depth limits their use, while for utility measures, the problem lies in the estimation of past utility (Geurs & van Wee, 2004; Páez et al., 2012). While people-based measures are more advanced, they require extensive data on individual-level time budgets, usually obtained from surveys. However, obtaining these data at a large geographic scale would require tremendous amounts of time and work (Geurs & van Wee, 2004; Pereira & Herszenhut, 2023; Siddiq & Taylor, 2021). Moreover, calculating past accessibility with a people-based measure is quasi-infeasible without previously conducted surveys. Place-based measures, on the other hand, require relatively little data, most of which already exists (e.g. OSM, GTFS). This data allows us to compute both past and current accessibility at large spatial scales (Geurs & van Wee, 2004; Siddiq & Taylor, 2021) Thus, this leaves place-based measures as the only option for this research.

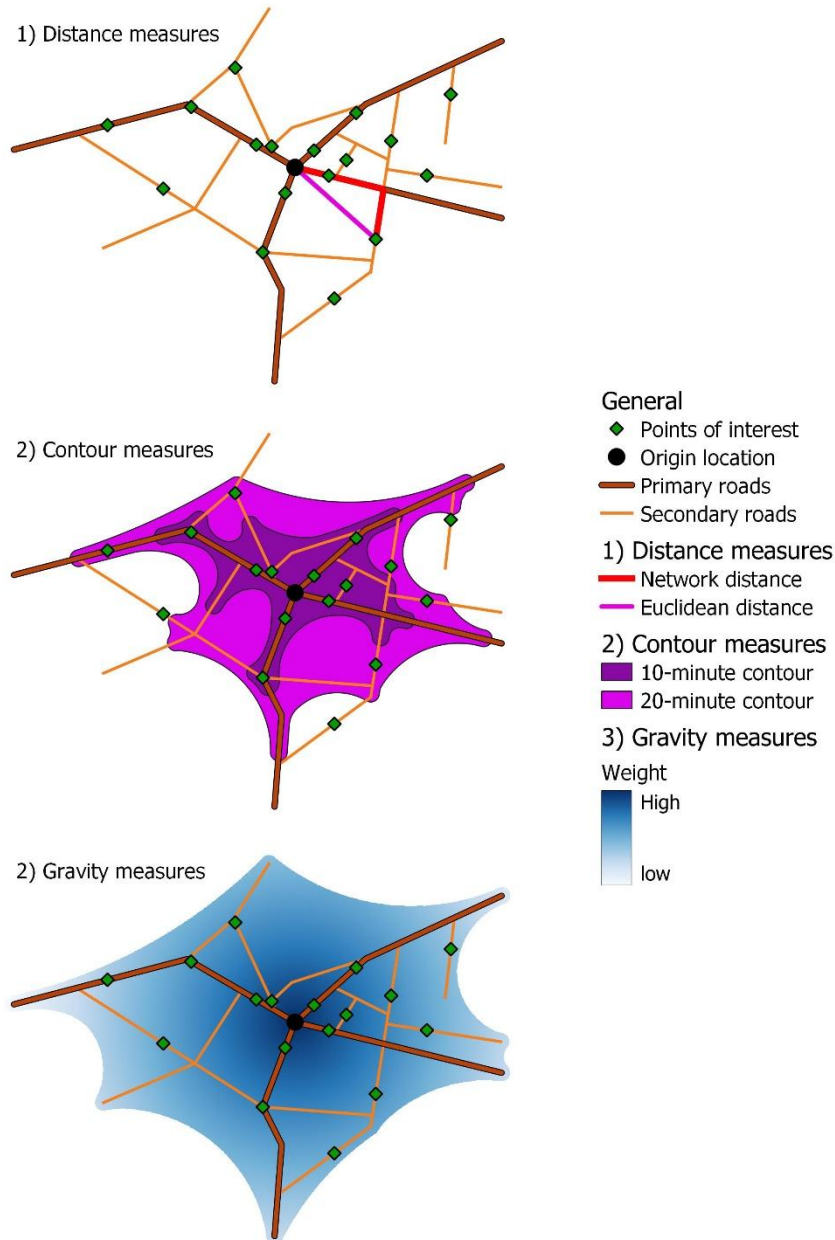


Figure 1: Illustrative example of three main place-based measures. 1) Distance measures based on network or Euclidean distance 2) Contour measures showing the opportunities reached within a user-defined time frame 3) Gravity measure showing a reduction in weights further away from the origin location

Of the three main place-based metrics, distance and contour measures are slightly too simplistic. They fail to evaluate the combined effects of transportation and land-use, making them too insensitive to small changes in the transit network. Although these measures are relatively straightforward to communicate and interpret, they also lack the ability to include even general human behaviour (Geurs & van Wee, 2004; Siddiq & Taylor, 2021). Gravity-based measure, on the other hand, satisfies most of the theoretical criteria, except for including detailed individual preferences. Nonetheless, the use of impedance functions allows for capturing even small changes in the public transit network and allows for modelling general human preferences, though it cannot capture the nuance of individual behaviour at

the same level as people-based measures (Geurs & van Wee, 2004; Horner & Downs, 2014; Pereira & Herszenhut, 2023). All combined, a gravity-based measure will be used in this study, given its sensitivity to public transit changes, suitability for application on large areas, and the partial inclusion of human preferences.

## 2.3 Flanders and public transit

The background of this rests on two pillars. The first is understanding the benefits and difficulties of establishing a public transit system, what accessibility is and how it can be measured. The second encompasses the study area, its historical context, policies surrounding public transport and previous accessibility studies.

### 2.3.1 Study area

Flanders and the Brussels-Capital Region (BCR) comprise the northern part of Belgium and have a combined area of 13,788 km<sup>2</sup> with just over 8 million inhabitants. Rather than having a core structure like cities of London and Paris, Flanders and BCR are comprised of a mixture of smaller villages, regional and larger cities. This can clearly be seen in Figure 2, the largest portion of the population lives in the Flemish Metropolitan Core Area (MCA), an area bounded by the cities of Leuven, Brussels, Ghent and Antwerp. However, a high population density exists across much of Flanders, with many higher-density settlements dispersed throughout it. These settlements are connected with a dense road network, often accompanied by ribbon development (Poelmans et al., 2022; Verbeek et al., 2014). As a result, Flanders is one of the regions with the highest degree of urban sprawl in Europe (Vermeiren et al., 2019). Although the polycentric pattern of settlements already started to take shape in the medieval era, the urban sprawl was only initiated due to several policies and laws promoting single-family households at the end of the 19<sup>th</sup> and the first half of the 20<sup>th</sup> century (De Decker, 2011). Urban sprawl was further encouraged at the end of the 1960s by the regional zoning plans, which crystallised the previous weak urban planning policies (Verbeek et al., 2014).

While there have been attempts to reverse the urban sprawl, it still persists and continues to this day; however, Flanders has committed to reducing net land take to zero by 2040 (Boussauw & Boelens, 2015; Government of Flanders, 2018). Nevertheless, public transit providers in Flanders will continue to operate in a region with a dense road network and a significant level of urban sprawl. Such sprawled spatial planning strains public transit operations by fragmenting service coverage, extending journey times and driving commuters toward private cars (Kakar & Prasad, 2020; Newman & Kenworthy, 2006; Zaman & Mei, 2000). In contrast, more compact development, with higher population and employment densities, mixed-use zoning, and transit stops within easy reach, facilitates public transport

efficiency and enhances walking and public transit usage (Kotharkar et al., 2014; Leck, 2006; Newman & Kenworthy, 2006). Despite these challenges, the 2018 Spatial Policy Plan emphasises the use of public transport and active transportation modes, and in light thereof, the Flemish Government completely overhauled the existing decree on public transportation (Government of Flanders, 2018; Vlaamse Overheid, 2025).

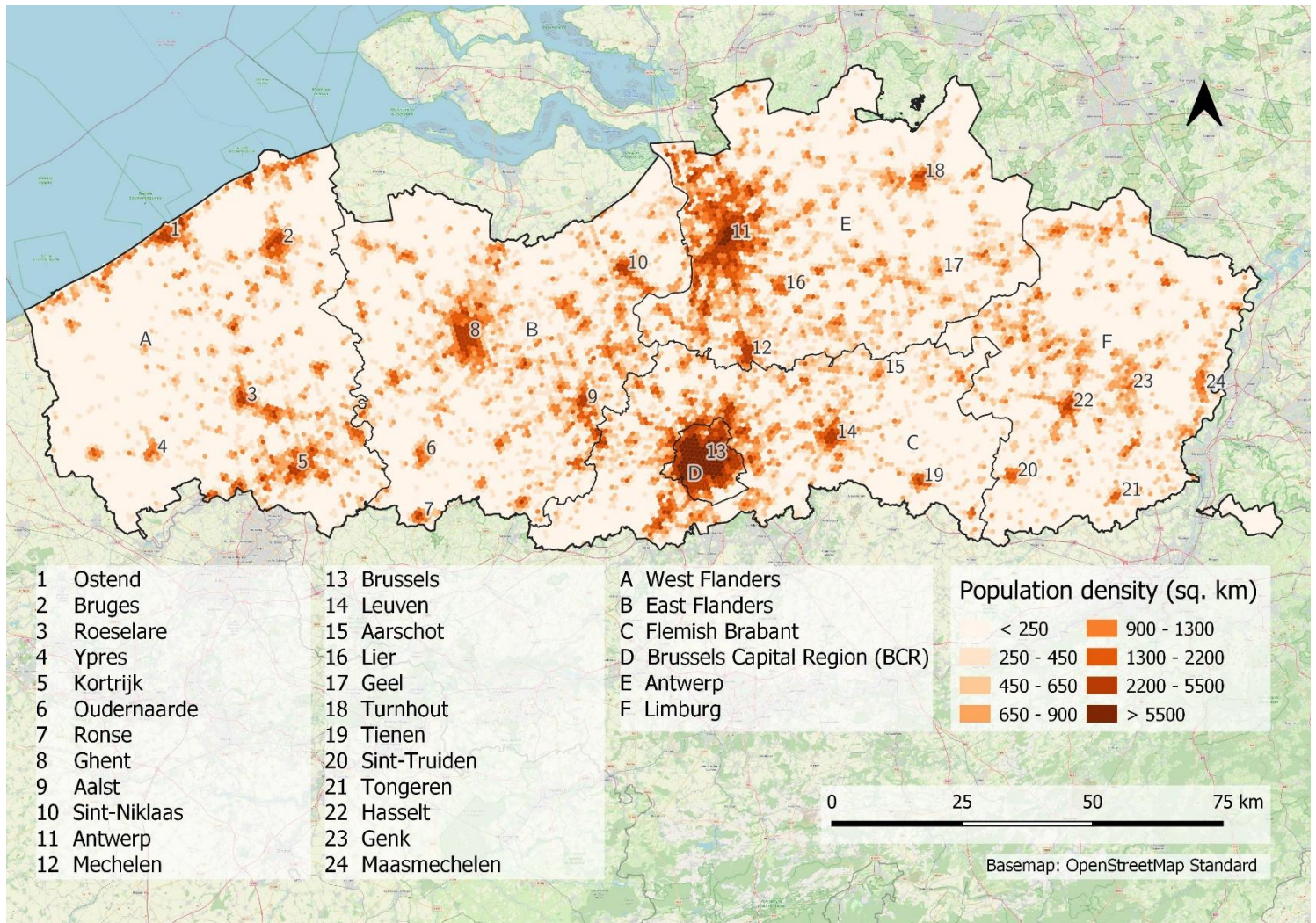


Figure 2: Population density in Flanders and the Brussels-Capital Region (BCR). Each population density bracket represents roughly 1,000,000 people. Larger and regional cities are number-coded to the map, provinces and the BCR are letter-coded.

### 2.3.2 Public transport policy

The original decree regarding public transportation in Flanders was the 2001 *Basismobiliteit* (basic mobility) decree. It stipulated the right to minimal access to public transportation services for every inhabitant in Flanders. This right was applied between 6:00 and 21:00 on weekdays and between 8:00 and 23:00 on weekends and holidays. The decree was modified in 2006 to include the obligatory presence of bus stops within specified radii from residential areas. Bus stops in rural areas were required to be within a 750m radius from dwellings, while bus stops in small-urban settlements and urban areas were required to be within a 650m and a 500m radius from dwellings, respectively. Consequently, additional bus routes were implemented in rural areas, while urban areas mainly saw improvements in public transit capacity and flow. In 2019, as a result of the Spatial Policy Plan, this decree was replaced with the *Basisbereikbaarheid* decree, abolishing the right to minimal access (Vlaamse Overheid, 2024).

With the 2019 'Basisbereikbaarheid' decree, Flanders significantly altered its approach to mobility. The new vision, called 'Hoppin', aims to improve public transport efficiency, sustainability and flexibility. Public transport changed from a supply-driven model to a demand-driven model, aiming to use resources more efficiently. Secondly, the decree introduces a four-tier hierarchical network comprised of a 'treinnet' (train network), a 'kernnet' (core network), an 'aanvullend net' (complementary network) and 'flexvervoer' (flex transit). In essence, the train network will form the backbone of public transport in Flanders, operating along major axes. The core network, comprised of buses and trams, will connect major residential areas and essential amenities. The complementary network will connect smaller cities and municipalities by bus, feeding into the two aforementioned networks. If public transit via these networks is not feasible, flex-transit, such as small vans, can be booked. All combined, the decree aims to construct an integrated transport landscape by establishing 'vervoer op maat' (tailored transit), where everyone can appeal to some form of transit depending on their needs. Examples are (the combination of) combi-mobility, flex transit, regular transit, transport for less mobile people and so on. To achieve this, Flemish municipalities were divided into 15 vervoerregio's (transit regions) in which local governments participate in the mobility-related challenges. In the end, all 15 transit regions were required to work out a regional mobility plan as a means to crystallise the medium- to long-term vision on mobility. The main objective of the new decree is for "schools, hospitals, business parks, and sports, cultural, and shopping centres to be fluently accessible for everyone" (Vlaamse Overheid, 2025).

The new decree was implemented in four phases. Phase 0, implemented on 01/01/2023, introduced around fifty quick wins to the transit network, but compared to the Basismobiliteit network, alterations were generally relatively limited. Phase 1 saw the first major changes. Implemented on 01/07/2023, it included roughly one hundred small and large measures, among which were alterations to the core and complementary network, as well as the flex transit. On 01/01/2024, phase 2 was implemented mainly with changes to the flex transit and only limited changes to the core and complementary networks, as most of those were postponed to a later phase. That phase was phase 3, implemented on 01/01/2025 and until now, the last phase implemented by 'De Lijn'. It is here that the changes postponed in the previous phases were implemented. (Rekenhof, 2024; Vlaams Parlement, 2023; Vlaamse Overheid, 2025).

During the implementation of the phases, the court of audit raised two main concerns. Firstly, De Lijn did not keep a detailed record of public transport network adjustments, making assessment of the changes more difficult, even though De Lijn stated that it had discussed the changes with the relevant transit regions. Secondly, there is a concern of blind spots in the tailored transit due to the numerous modifications, an issue also voiced by protests and the media (Rekenhof, 2024; VRT NWS, 2024a). As the new Flemish public transit policy focuses on efficiency and increased streamlining, the question not only becomes where, to what extent and how accessibility changes come to be, but also who experienced the brunt of these changes.

## 2.4 Empirical studies of public transit accessibility

Over the past years, much research has been conducted that has advanced our understanding of how public transport accessibility shifts in response to service changes and network evolution. Yet many studies stop at straightforward before-and-after snapshots, focus on a single city or a couple of corridors, or treat accessibility as a black-box without trying to unpack the different components that influence it. Therefore, four aspects important for this research but understudied in the literature will be discussed: time horizon, spatial scale, modal and network alterations, and equity impacts.

### Time Horizon

Several scholars have examined short-term accessibility variations resulting from public transit alterations. Farber & Fu (2017) produced minute-by-minute travel-time cubes for three U.S. cities before and after a transit network change, offering high temporal granularity, although the network changes and spatial extent were relatively limited.

Similarly, Pereira & Herszenhut (2023) assessed existing and projected subway scenarios in Fortaleza, Brazil, but also focused on only two timestamps. Benenson et al. (2011) calculated accessibility changes at the building and stop level in Tel Aviv, Israel, following a bus-line reform, only examining immediate impacts without tracing how benefits or losses accrued over the months or years before. Studies that span longer periods, such as Foth et al. (2013) and Vigiúé et al. (2023), which analysed accessibility for disadvantaged groups over a decade or longer, mainly put emphasis on the people-aspect rather than the geography and magnitude of accessibility change itself. Limited work to date focuses on a multi-stage policy rollout with repeated accessibility measurements across phases. This research analysis of long-term accessibility change between 2016 and 2025, with the implementation of the 'Basisbereikbaarheid' policy between 2023 and 2025, tries to fill this methodological gap.

### Spatial Scale

The spatial scale is also an important dimension of this study. Much of the literature focusing on public transit changes limits its scope to city-level accessibility, leaving rural and regional dynamics underexplored. Benenson et al. (2017), Farber & Fu (2017), Lee & Miller (2018), Pereira & Herszenhut (2023) and Vigiúé et al. (2023) Each focuses on city-level systems, investigating intra-urban dynamics of change but offering little insight into non-urban areas. There are studies that investigate public transport accessibility on a large scale. Fransen et al. (2015, 2019) and Verachtert et al. (2023) It maps public transit accessibility across Flanders, but does so at singular moments rather than tracing changes over time. Moreover, Verachtert et al.'s (2023) Access to transit stops does not fully capture public transport accessibility. By analysing accessibility at a large scale, this research can also assess accessibility of long-distance trips such as rural-urban or inter-city trips. In turn, this allows us to examine whether alterations to the public transit network have different effects at local or regional levels, similar to Verachtert et al. (2023), who assessed accessibility for basic, regional and metropolitan services.

### Modal and Network Alterations

Truly understanding why accessibility changes require more than information on the transit network alterations. It demands an understanding of walking, waiting, in-vehicle time, travel time changes throughout the day and network frequency and network configuration shifts. Studies on accessibility do sometimes include information on travel time changes throughout the day (Farber & Fu, 2017; Fransen et al., 2015) or even the frequency of the transit network (Stępnia et al., 2019). However, they do not fully integrate these findings into

explanations of accessibility dynamics. The absence of studies that couple such components to changes in accessibility limits the understanding of how this dynamic works.

### Equity Impacts

Lastly, a minor focus of the study also lies on equity in the public transport changes. Public transport equity is a well-researched topic, with many studies on different aspects of equity and transport justice, such as (a combination of) income, age, race and so on (Bocarejo S. & Oviedo H., 2012; Delbosc & Currie, 2011; Foth et al., 2013; Gössling, 2016; Vigué et al., 2023). In Flanders, similar kinds of studies have been conducted. Fransen et al. (2015, 2019) Studied private and public transit accessibility of disadvantaged people to jobs and did research on identifying mismatches between socially driven demand for public transport and the transit supplied by the transit agencies. Vandenbulcke et al. (2009) Looked at spatially equitable car accessibility to cities and railway stations throughout Belgium and how it differed between on-peak and off-peak times. Studies by Benenson et al. (2017), Farber & Fu (2017) and Pereira & Herszenhut (2023) Touch on equity outcomes of accessibility change, but do not compare urban versus rural patterns. By linking accessibility changes to the population density of home locations, this study aims to examine whether urban or rural areas were more affected by the changes.

Existing studies rarely bring all four dimensions together, instead addressing one or two. In contrast, this research tracks accessibility phase by phase over a ten-year span (2016–2025) for the entirety of Flanders and the BCR. It also unpacks the individual components related to accessibility, such as service frequency, route layout, stop placement, and timetable alterations, to see how they influence accessibility and its changes. Finally, the study compares how these changes vary between high- and low-density areas, providing a multi-perspective view of long-term accessibility dynamics. In the next section, I will navigate the course for this research trip by explaining the operationalisation of the accessibility measure and the calculation procedure to answer the research questions.

### 3 Methodology: Planning the trip

*How and to what extent did local accessibility to secondary schools and regional accessibility to museums evolve across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025, and how do these trajectories differ between high-density and low-density areas?*

*How have changes in service frequency, route configurations, stop locations and timetables across each phase of the Basisbereikbaarheid rollout (phases 0–3) and cumulatively between 2016 and 2025 driven the observed shifts in public transport accessibility?*

The plan to address these research questions is presented in this chapter. First, the operationalisation of the gravity-based accessibility metric will be thoroughly explained, followed by a section on the calculation procedure utilised to answer the research questions.

#### 3.1 The gravity measure in this study

To shortly recap, gravity measures consider all reachable opportunities from a given origin location, whereby each opportunity is gradually discounted as travel costs increase. Consequently, easier-to-reach opportunities contribute more to accessibility; those that are harder to reach contribute less. This discounting is the result of applying an impedance function to the travel cost. So, before moving on to the operationalisation of the accessibility measure, it is necessary to take a detour to discuss the impedance function used in this research.

##### 3.1.1 The impedance function

Impedance functions convert travel times into weights between 0 and 1, dictating how rapidly opportunity values decay with increasing travel time. They are typically constructed from empirical travel data, selecting an appropriate mathematical form (Fig. 3) and calibrating key parameters. The choice of the parameters and form can depend on the transportation modes used, the amenities analysed and general human behaviour (Iacono et al., 2008; Levinson & King, 2020; Martínez & Viegas, 2013). When the desired parameters and form are obtained, the impedance function becomes straightforward to integrate into the gravity measure. The mathematical form and parameters allow impedance functions to obtain high versatility, but this also comes with some drawbacks. While general human behaviour is included, other factors as public transit cost and individuals' physical ability are not included. Additionally, estimating key parameters and selecting a

mathematical form is not a straightforward process given the numerous options. (Geurs & van Wee, 2004; Iacono et al., 2008; Levinson & King, 2020).

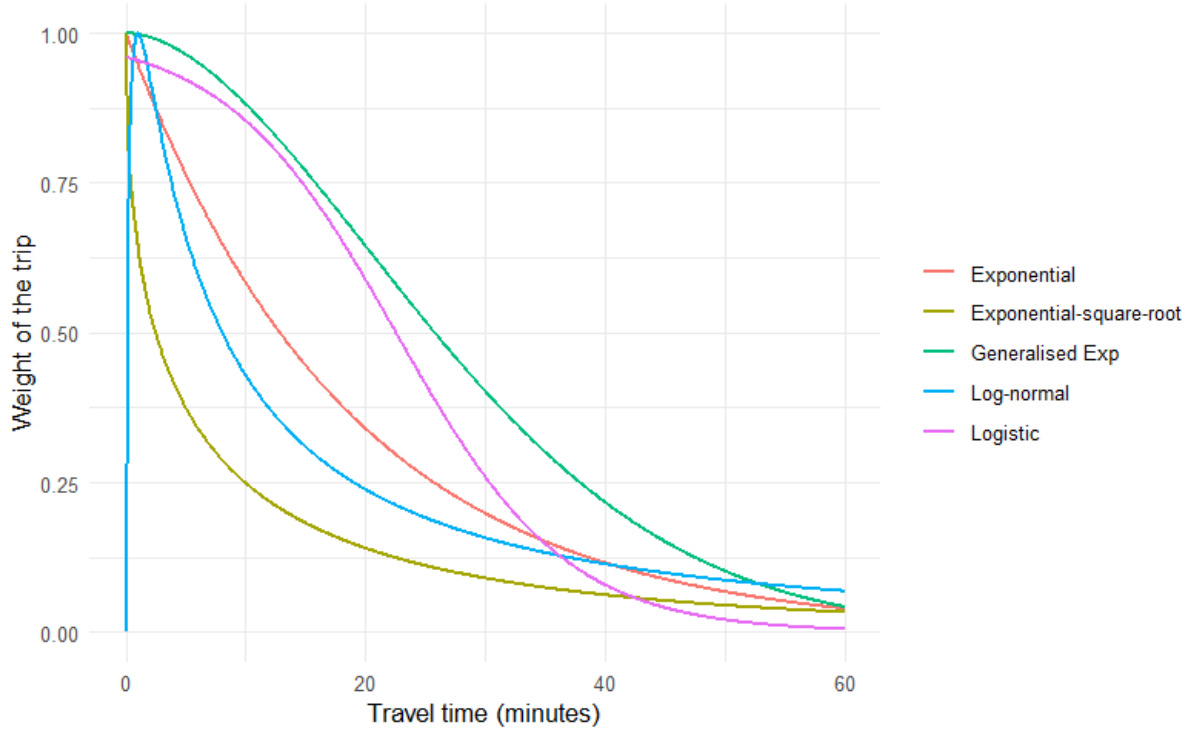


Figure 3: Mathematical form of common impedance functions. Based on data from Feldman et al., (2012), Levinson & King, (2020) and Wu et al. (2019)

So, what impedance function form should be used in this research? Some researchers have put forward the exponential function as the best representation for human behaviour (Handy & Niemeier, 1997; Levinson & King, 2020). However, this function, like most others, uses a decay parameter (often represented as  $\beta$ ) to directly estimate how strong the discount should be. These decay parameters can be sourced from planning models, earlier research or built from scratch, but they vary widely across contexts such as time-of-day, modes of transportation, opportunities of interest and regions (Haynes & Fotheringham, 2020; Levinson & King, 2020; Martínez & Viegas, 2013). If no strategic planning models or previous assessments on decay parameters have been executed, it might prove difficult to develop one. While researchers as Merlin (2020) and Papa & Coppola, (2012) To offer solutions to this problem, I elect to use a logistic impedance function proposed by Martínez & Viegas (2013), given as  $\frac{\exp(a_o - b_o * x)}{1 + \exp(a_o - b_o * x)}$ . This type of function does not use a  $\beta$ -decay parameter, but utilises easier-to-estimate parameters;  $a_o$  and  $b_o$  Respectively shift and steepen the curve;  $x$  represents the travel time.

Martínez & Viegas (2013) calibrated these two parameters by differentiating survey travel times in 'close' and 'far' using the perception of survey respondents. They assumed an

average travel time considered 'close' would obtain a value of 90% of the maximum impedance value, while for 'far', their value would be 10%. However, these values are not rigid and can be modified if you want to place more emphasis on opportunities located nearby or further away (e.g. 20% for 'far', 80% for close'). The travel times representing the chosen values for 'close' and 'far' will then be used to calibrate the parameters  $a_0$  and  $b_0$  as follows:

$$'close' = 0.9 = \frac{\exp(a_0 - b_0 * \text{travel time close})}{1 + \exp(a_0 - b_0 * \text{travel time close})} \quad \text{and} \quad 'far' = 0.1 = \frac{\exp(a_0 - b_0 * \text{travel time far})}{1 + \exp(a_0 - b_0 * \text{travel time far})}$$

Important to note is that different travel times can be deemed 'close' or 'far' depending on the opportunity considered. So, travel times considered 'close' for secondary schools will differ from those considered 'close' for museums.

By using survey travel time data, Martínez & Viegas (2013) found that this function is able to fit empirical data better than other impedance functions. However, it should be noted that this approach has mainly been applied for short travel times, contrasting with the research's focus on all reachable local and regional destinations, which can result in high travel times. The logistic impedance function has already been applied in Flanders in a study by Verachtert et al. (2023), although they used it for estimating accessibility to transit stops rather than actual public transit accessibility. As a result, their parameters cannot be recycled for this research. But overall, a logistic impedance function offers a solid balance between complexity, modifiability and performance

### 3.1.2 Operationalisation of the accessibility measure

As this research focuses on local and regional accessibility, secondary schools and museums are used as proxies. Access to secondary schools is important as students typically lack a driver's license, increasing their dependency on modes as public transit. Additionally, school hours are relatively rigid, and they can only be visited during the week, presenting a distinctive timeframe in which accessibility can be calculated. Accessibility to museums, on the other hand, reflects the regional dynamic, as museums are more concentrated in the larger cities. A second difference is the museum's more flexible visiting hours during both weekdays and the weekend. The accessibility to these two amenities will be calculated at four different years (2016, 2023, 2024 and 2025) at relevant timestamps to evaluate the changes of each implemented phase of the Basisbereikbaarheid decree. To simplify accessibility calculations, one representative week for each year will be used in which accessibility will be computed at the relevant time periods. The full overview of the operationalisation of the accessibility measure is provided in the Figure below (Fig. 4).

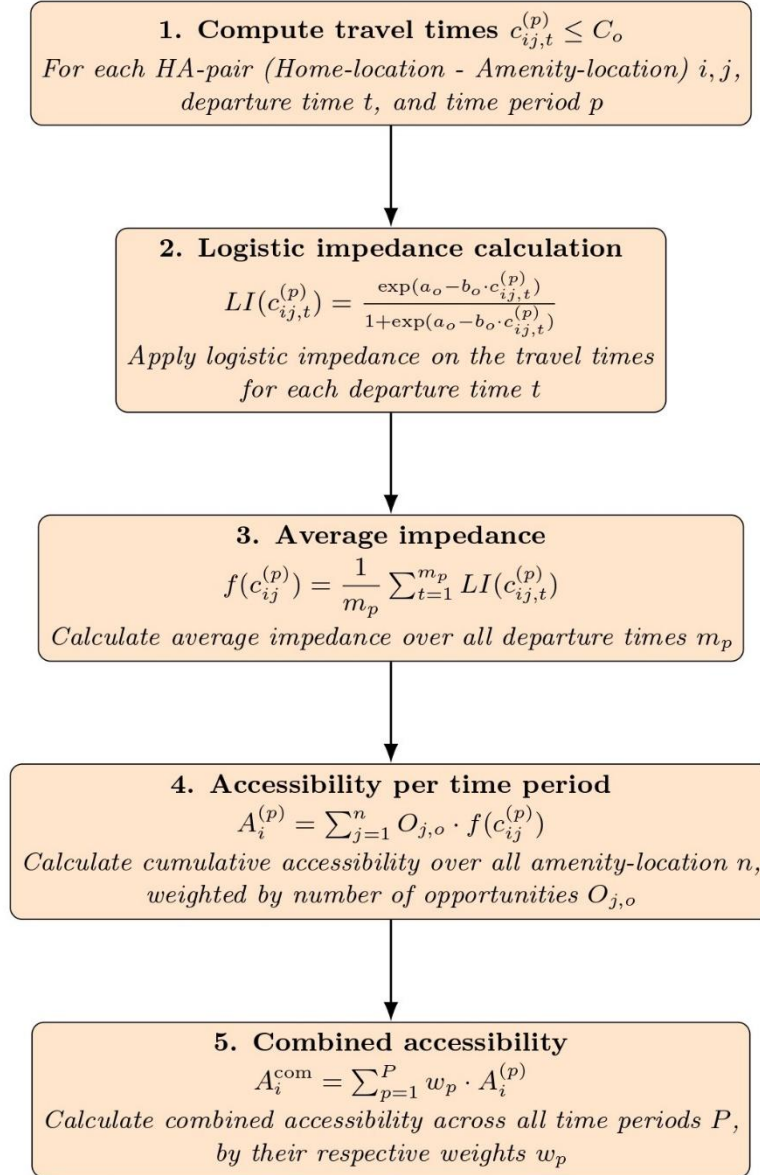


Figure 4: Full overview of the operationalisation of the gravity measure used in this study

Before discussing the operationalisation, a clarification must be made regarding the semantics. Throughout the methodology, results and discussion, ‘home-location’ and ‘amenity-location’ will be used instead of ‘origin’ and ‘destination’. The reason is straightforward: both home -and amenity-locations alternate as destinations and origins. For example, home locations are the origins in the morning travel time calculations and become destinations for evening travel time calculations. Consequently, it would be incorrect to describe either home-locations or amenity-locations consistently as origin or destination.

That being mentioned, the first step in the operationalisation is calculating the travel times (step 1, Fig. 4). To compute all the necessary trips, trips will be calculated between all home -and amenity-location pairs  $i, j$  for a departure time  $t$  (e.g. 08:00) at a time period  $p$  (e.g. morning). Calculations are made for all possible home–amenity location (HA) pairs, during all relevant time periods and departure times making up those time periods. While the travel time between all HA-pairs will be assessed, travel times exceeding the maximum travel cost  $C_o$  will not be included in further calculations. This reduces computational requirements significantly, as travel times equal to or higher than  $C_o$  obtain an impedance value of near zero.

After all travel times are computed, they can be parsed through the logistic impedance function (step 2, Fig. 4). The function itself is given as  $\frac{\exp(a_o - b_o \cdot c_{ij,t}^{(p)})}{1 + \exp(a_o - b_o \cdot c_{ij,t}^{(p)})}$ , with the decay parameters  $a_o$  and  $b_o$  depending on the type of opportunity  $o$  considered. As mentioned above, these parameters are estimated from opportunity-based travel times, and their calculation will be described in the calculation procedure section. Parameter  $c_{ij,t}^{(p)}$  represents the travel cost (here: travel time) between the home location  $i$  and amenity-location  $j$  for a specific time period  $p$  and travel time  $t$  within that time period. For example, a 25-minute travel time at 08:00 ( $t$ ) on a Monday morning ( $p$ ). The travel time will then be plugged into the impedance function to obtain the impedance value of one trip (e.g. Monday morning at 08:00), depicted as  $LI(c_{ij,t}^{(p)})$ .

Each time period  $p$ , is comprised of a set of departure times  $m_p$ , consisting of individual departure times  $t$ . For example, Monday morning from 08:00 to 10:00 ( $m_p$ ) with departure times every 5 minutes. Consequently, travel times have to be calculated for 24 departure times, which all have to be parsed through the impedance function. To deal with this, the following function will be used:  $f(c_{ij}^{(p)}) = \frac{1}{m_p} \sum_{t=1}^{m_p} LI(c_{ij,t}^{(p)})$ . Impedance values for all departure times from a home location  $i$  to an amenity location  $j$  in the respective time period  $p$  that were previously calculated ( $LI(c_{ij,t}^{(p)})$ ) are summed, while subsequently divided by the total number of departure times  $m_p$ , with  $f(c_{ij}^{(p)})$  as the outcome (step 3, Fig. 4). This latter parameter thus indicates the average impedance value from one home location  $i$  to one amenity-location  $j$  for all departure times  $t$  in the considered time period  $p$ .

In step 4 of Figure 4, the accessibility  $A_i^{(p)}$  at a home-location  $i$  for a time period  $p$  is calculated using the following function:  $A_i^{(p)} = \sum_{j=1}^n O_{j,o} \cdot f(c_{ij}^{(p)})$ .  $A_i^{(p)}$  is calculated by computing average impedance value between a home-location  $i$  and amenity-location  $j$  for all departure times in the considered time period  $f(c_{ij}^{(p)})$  (previous step) and multiplying

it by the number of opportunities  $O_{j,o}$  at the amenity-location  $j$  for a specific type opportunity  $o$  (secondary schools or museums). As the definition of accessibility states that the focus will lie on access potential, the accessibility value at home-location  $i$  will be summed for all amenity-locations  $n$  that were reached, as illustrated by the summation function. This provides a singular accessibility value per time period  $p$  at a home-location  $i$ . In full, it is the cumulative accessibility to all amenities within the maximum allowed travel cost, averaged over all departure times within the considered time period.

However, there are multiple time periods that must be taken into consideration. A return trip is equally as important as an outward trip. For secondary schools, for example, accessibility matters in the morning, while accessibility from school to home matters in the evening. Therefore, a final step is needed (step 5 of Figure 4). In the following function:  $A_i^{com} = \sum_{p=1}^P w_p \cdot A_i^{(p)}$ , the accessibility  $A_i^{(p)}$  for each time period  $p$  will be summed over all time periods  $P$  and weighted by each time period's relevance  $w_p$ . This results in a singular combined accessibility value over all time periods:  $A_i^{com}$ . To illustrate the importance of weighting, accessibility to secondary schools in the evening and morning is relatively speaking more important than on a Wednesday at noon, as the latter only occurs once a week. Consequently, the latter period will contribute less to the overall accessibility value. The specific details regarding weights and time periods will be described in the calculation procedure. A simplified example of the conceptualisation of the gravity measure is provided in Figure 5, going over each of the five steps.

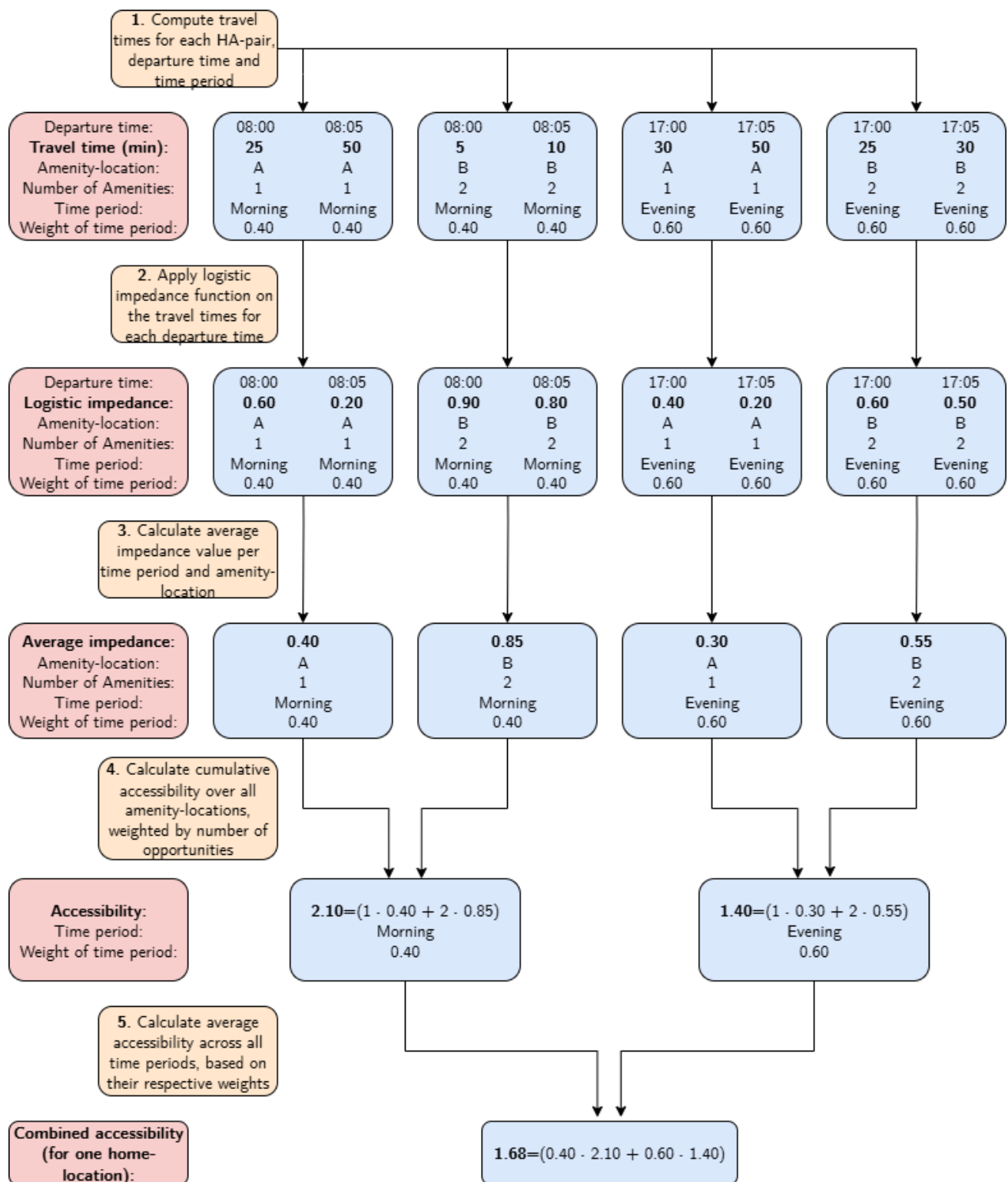


Figure 5: simplified example of the working of the gravity accessibility measure along its five core compartments.

### 3.2 Calculation procedure

The procedure used to address the research questions consists of four steps, illustrated in the flowchart below (Fig. 6). Data gathering encompasses obtaining relevant datasets. In the next phase, data will be pre-processed by filtering, cleaning and preparing the data for the travel time calculations in step 3. There, travel times to each type of amenity will be calculated, and the gravity measure will be applied to derive accessibility. The results from this phase will be used to visualise and analyse accessibility based on the two research questions. The following sections elaborate on these four steps.

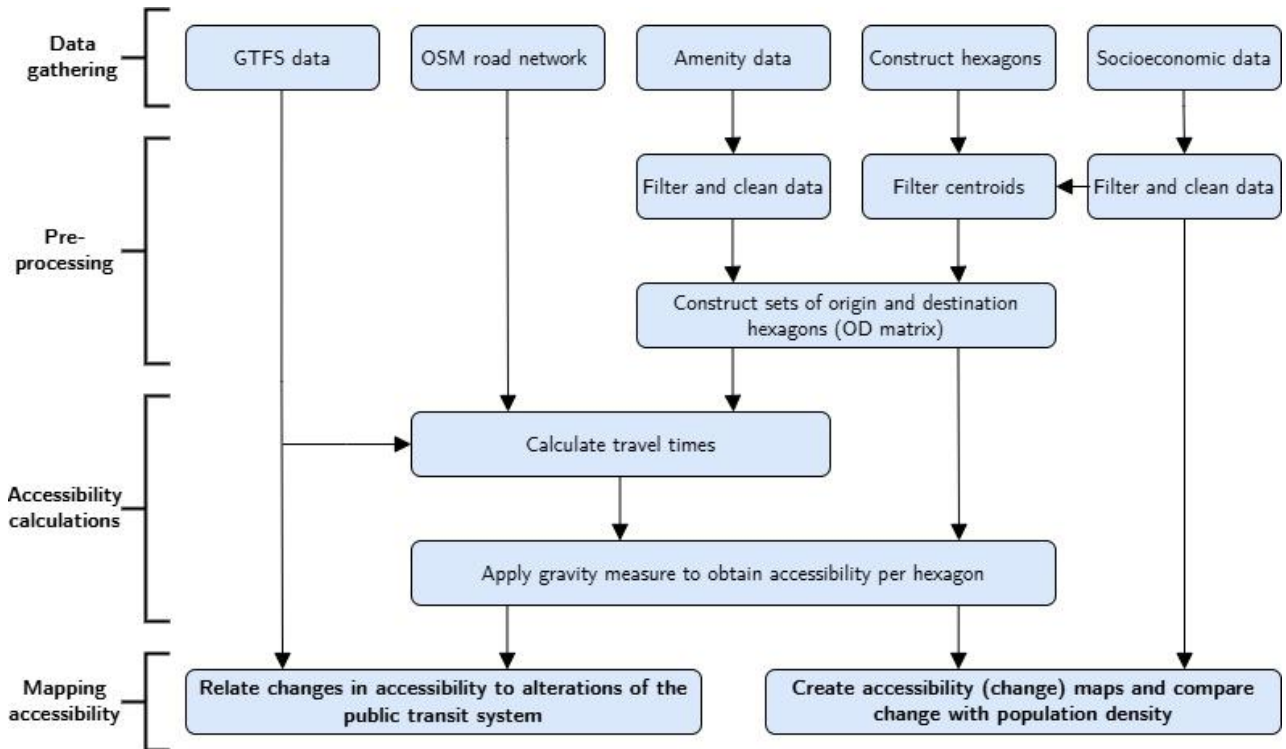


Figure 6: Calculation procedure used to answer this study's research questions (in bold)

#### 3.2.1 Data requirements

The data sources used in this research are outlined below. It includes public transport data, spatial data, data on opportunities and socioeconomic data. This section will provide information on the different types of data and how they will be used. Where it will be used throughout the research is discussed in the subsequent sections.

The public transit data used in this research are GTFS (General Transit Feed Specification) data from the public transport services operating in Flanders and the BCR. The 'Waterbus' is responsible for the ferries across the Scheldt River near Antwerp. 'De Lijn' provides bus

and tram services operating throughout Flanders. The NMBS/SNCB (National Railway Company of Belgium) offers train services throughout Belgium. The MIVB/STIB (Brussels Intercommunal Transport Company) operates bus, tram and metro services in the BCR. Lastly, the TEC provides bus and tram services in Wallonia. The GTFS data contains information on the routes, stops and timetables of the network of these public transport services. To capture the long-term trends in public transit accessibility, data around the middle of March will be used for every year. This date ensures that timetable changes implemented earlier in the year by De Lijn in January and the NMBS in December are incorporated and potentially already slightly adjusted. Additionally, this period avoids Easter and spring breaks, ensuring representative calculations. One exception is the usage of GTFS data from December 2023, as no data was publicly available for March 2023. This also means that phases 0 and 1 of the Basisbereikbaarheid policy cannot be assessed separately. The data for 2023, 2024 and 2025 are obtained from Professor Poorthuis' research group, while the 2016 data is obtained from OpenMobilityData (2024).

To compute the travel times via the r5r routing engine (Pereira et al., 2021), an OpenStreetMap (OSM) road network data (BBBike, 2024) must be provided so walking times can be properly calculated and home -and amenity-locations can be snapped to the road network. The OSM road network data used is from November 2024 and will be used for all four years for which accessibility will be calculated, as this is more straightforward and enhances comparability between years. Additionally, the study area will be divided into small hexagons of roughly  $0.75 \text{ km}^2$  by utilising the H3 library (Cooley, 2024), with each hexagon's centroid serving as an origin or destination. All programming required will be executed using R.

As mentioned, the research focuses on two amenities mentioned in the Flemish government's Basisbereikbaarheid decree: secondary schools and museums. The data on secondary schools was downloaded from Geopunt Vlaanderen (Vlaams Ministerie van Onderwijs en Vorming, 2024), while the data on museums was obtained from OSM (OpenStreetMap contributors, 2024) (Fig. 7). Raster socioeconomic data on population and age groups at a resolution of  $100\text{m}^2$  were sourced from WorldPop (Bondarenko, M. et al., 2020b) (Fig. 2). Both opportunity data and population data will be held constant across all years because of the limited historical timestamps of the data. Nevertheless, this helps to isolate the effect of timetable changes, although ideally, changes in population and opportunities should be incorporated as they can impact the level of accessibility (Geurs & van Wee, 2004).

The other socioeconomic data used encompasses six survey editions of the Onderzoek Verplaatsingsgedrag (OVG) Vlaanderen (Research travel behaviour Flanders) from 2015-

2016 to 2021-2022 (Janssens et al., 2018, 2020a, 2020b, 2023; Reumers et al., 2016, 2017). These surveys provide empirical data regarding travel times to schools by main mode of transportation. The data from these surveys will be aggregated over all years to obtain a general insight into the average travel times to secondary schools and maintain simplicity. For museums, similar disaggregated data is not available, so this study has to rely upon a singular Dutch report stating people's average travel time to museums (DSP-groep, 2011). The museums and secondary school travel time data will be used to estimate the travel times representing 'close' and 'far' to calibrate the impedance functions.

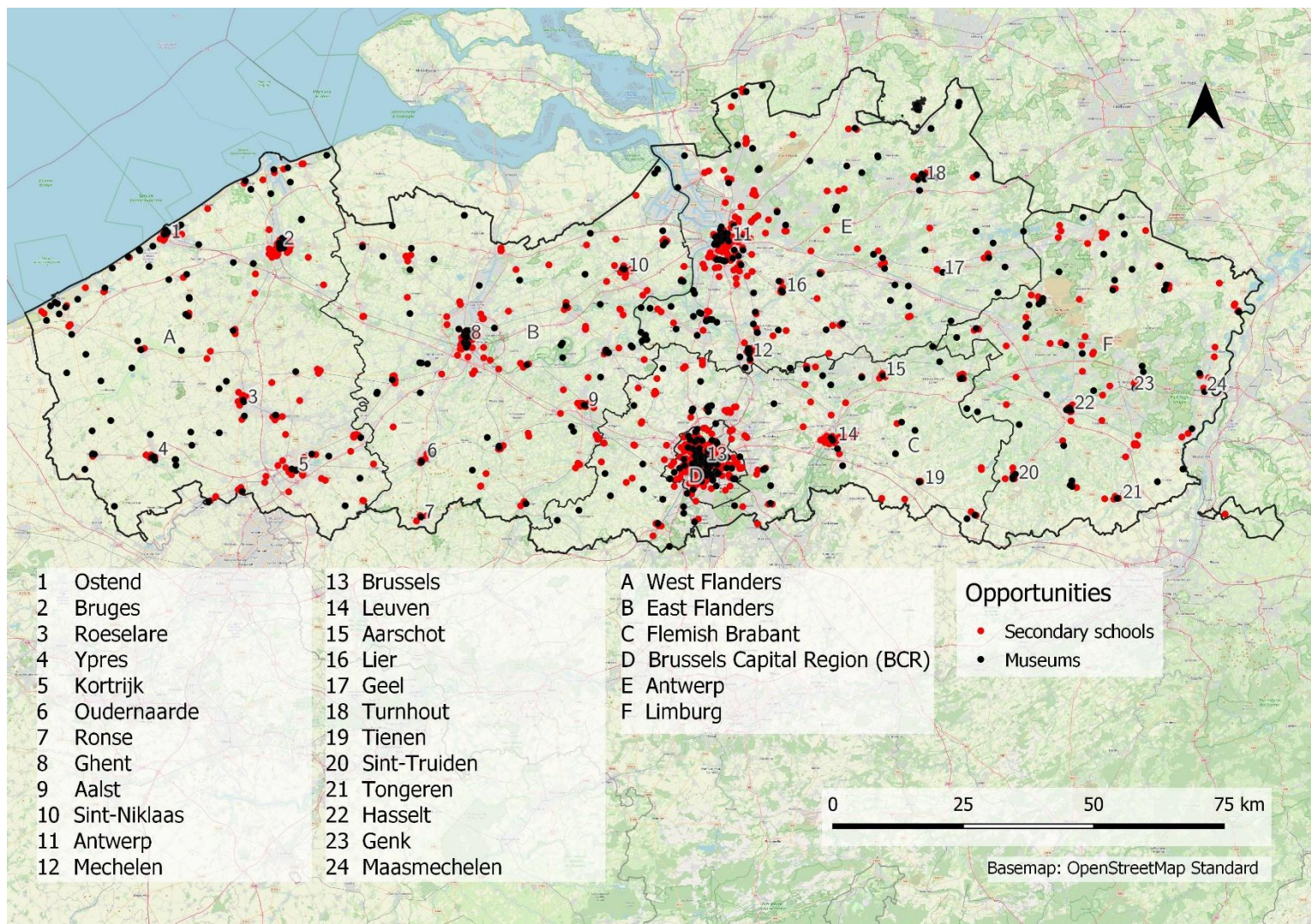


Figure 7: Overview map of the location of museums and secondary schools throughout Flanders and the BCR.

### 3.2.2 Preprocessing

Most datasets require preprocessing before being used to calculate travel times. Regarding the amenities, only the secondary school data required preprocessing. The museum's data will be used as obtained from OSM, which includes both small and large museums. For the secondary school data, only schools in 'Voltijds gewoon secundair onderwijs' (full-time regular secondary education) are kept to focus on regular secondary education. Schools dedicated to first- and second-year secondary education are excluded to simplify calculations. Duplicate entries, where schools with the same name occur more than once in the same municipality, are also removed. It is possible that inaccuracies may still persist due to the limitations of the dataset or cross-municipality collaboration of schools.

For the hexagon data, this step includes adding the population data and constructing their respective centroids. Firstly, the population data will be written from each raster file to the hexagon file, where all pixels overlapping with a hexagon contribute population to that hexagon relative to the amount of overlap. To enhance computation times, hexagons that end up having a total population of 10 people or less will be excluded. Secondly, centroids of each hexagon will be constructed and snapped to the OSM road network, which is necessary for the r5r routing engine to properly function. However, this can offer some complications; if a centroid is snapped to the road network outside its respective hexagon, both the centroid and the hexagon will be removed from the analysis. A centroid located in another hexagon will portray the accessibility of the hexagon it is located in, not the accessibility of the hexagon it actually belongs to.

The hexagon dataset resulting from the filtering above will also be overlaid with the amenity data. Only hexagons containing at least one amenity are retained, with the amenity count stored as a variable. Using the hexagon-linked amenities instead of the exact amenity locations allows for curbing calculation times at the price of introducing minor inaccuracies in the calculated travel times. The result is three different hexagon/centroid data sets that will serve both as origins and destinations: the home-locations representing the complete hexagon set for the entirety of Flanders and BCR, and the amenity-locations representing the museum hexagon set and the secondary school hexagon set.

### 3.2.3 Accessibility calculations

Travel times are calculated between the complete hexagon set and the museum's hexagon set, and between the complete hexagon set and the secondary school hexagon set for March 2016, December 2023, March 2024 and March 2025. Before calculating the travel times, some general parameters have to be discussed. Firstly, the walking speed in this research is set to 4.5km/h as a compromise between Levinson & King (2020) who proposed a speed of 5km/h and Verachtert et al. (2023) who used a speed of 4km/h in their study. The maximum walking time is set to 30 minutes per leg of the trip. This implies that one can walk up to 30 minutes to a transit stop and again up to 30 minutes when leaving the transit. A value of 30 minutes of walking is quite large, but this study focuses on potential accessibility. Additionally, using a large maximum walking time is also suggested by Levinson & King (2020) who put forward using the 95<sup>th</sup> percentile of the empirical data on walking times as a maximal limit. Similarly, De Lijn uses a maximum walking distance of 2500m in its trip planner. On the other hand, studies also often suggest using maximum walking distances lower than 1000m (Chapleau & Morency, 2005; El-Geneidy et al., 2010; Mavoa et al., 2012), but these studies often focus on urban environments. Lastly, the maximum number of transfers should also be considered. Owen & Murphy (2018) mention that 90% of transit trips in US cities have a maximum of two transfers. Since this research focuses on the accessibility potential, the value is set to three to allow flexibility in the trip routes, but not higher, as this again would have a negative impact on the computation times. Apart from these general parameters, some amenity-specific parameters also need to be discussed.

#### 3.2.3.1 Secondary schools

To calculate travel times from home locations to secondary schools, departure times, and maximum travel time should also be set up properly. The relevant timeframes for secondary schools are straightforward: morning, evening and Wednesday afternoon. In the morning period, travel times are computed between 07:00 and 09:00 on a Monday. A maximum travel time of 75 minutes is applied; however, destinations should be reached at the latest at 09:00. This timeframe aligns with the earliest starting schools at 08:00 (Vlaamse Overheid, n.d.), while still providing some margin.

For noon and evening calculations, travel times will be computed from secondary schools to the home locations. Evening travel times are computed between 15:00 and 17:00 on a Monday, again with a 75-minute maximum travel time. This time period is selected since secondary schools are obliged to end between 15:00 and 17:00 (Vlaamse Overheid, n.d.). Lastly, on Wednesdays, most schools do not have classes in the afternoon (Vlaamse

Overheid, n.d.). Therefore, travel times from schools to hexagon centroids will also be calculated on Wednesdays between 11:30 and 13:00 with the same maximum travel time. The Monday morning and evening calculations will be used as a proxy for the other days of the week (excluding Wednesday evening), as public transport timetables remain the same throughout the weekdays. Also note that this research will always use a 5-minute interval for every timeframe, as the loss in precision compared to 1-minute intervals is negligible, while decreasing computation times fivefold (Stępnia et al., 2019).

To set up the impedance function, estimations are needed to determine what travel times represent 'far' and 'close'. Since no stakeholder or survey values for 'close' and 'far' can be found, I used the 10<sup>th</sup> and 90<sup>th</sup> percentiles of the aggregated OVG travel time data to define the travel times representing 'close' and 'far', respectively. This resulted in 'close' travel times being defined as 6.92 minutes and 'far' travel times as 38.12 minutes, with the calibration looking as follows: 'close' = 0.9 =  $\frac{\exp(a_0 - b_0 \cdot 6.92)}{1 + \exp(a_0 - b_0 \cdot 6.92)}$  and 'far' = 0.1 =  $\frac{\exp(a_0 - b_0 \cdot 38.12)}{1 + \exp(a_0 - b_0 \cdot 38.12)}$ . When solving the mathematical system for parameters  $a_0$  and  $b_0$ , values of 3.17 and 0.141, respectively, were derived (Fig. 8). A logistic impedance function with these two parameters will give an accessibility value of nearly zero for a travel time of 75 minutes, making it a valid maximum travel time.

After obtaining all parameters for the impedance function, steps 2 to 4 of the operationalisation can all be completed. Lastly, step 5 can be executed as well since three accessibility values per home location are obtained as output of step 4. These three values represent morning, noon and evening accessibility, which will get a respective weight of 0.5, 0.1 and 0.4. 5/10 trips per week to school are in the morning, 1/10 is at noon to home, and 4/10 are in the evening returning from school. Calculating the weighted average accessibility value of these time periods yields the combined accessibility value per home location.

### 3.2.3.2 Museums

For the museums, the timeframes and days for the calculations are quite different. A morning timeframe between 08:00 and 11:00 and an evening timeframe between 18:00 and 21:00 will be used. Importantly, these timeframes will be calculated both for a Monday and a Sunday, with Monday representing the weekdays, while Sunday represents the weekend. A distinction between these two is made since public transit services differ between weekends and weekdays. Why are these timeframes selected? This study assumes that most people would make a day trip when visiting museums, combining it with other activities,

which is supported by research from the University of Antwerp (Verboven & Schramme, 2023). The morning timeframe represents the movement from the home location to the reachable museums, while the evening timeframes represent the opposite direction.

Regarding the impedance function for museums, things differ slightly from secondary schools. The report completed by DSP-groep (2011) only contains information on the average travel time to museums (63 minutes), meaning that the 10<sup>th</sup> and 90<sup>th</sup> percentiles cannot be established. Therefore, the same relative distance from the average value to the 10<sup>th</sup> and 90<sup>th</sup> percentiles will be used as seen for secondary schools. The average, 10<sup>th</sup> percentile and 90<sup>th</sup> percentile for secondary schools are 6.92 minutes, 20.82 minutes and 38.12 minutes, respectively. The relative distance between the 10<sup>th</sup> percentile and the average is roughly a factor of three, so the 10<sup>th</sup> percentile for museums becomes 19.94 minutes. The relative distance between the 90<sup>th</sup> percentile and the average travel time is roughly a factor of two, so the 90<sup>th</sup> percentile for museums becomes 114.44 minutes. Using these values to calibrate the impedance function: 'close' =  $0.9 = \frac{\exp(a_0 - b_0 \cdot 19.94)}{1 + \exp(a_0 - b_0 \cdot 19.94)}$  and 'far' =  $0.1 = \frac{\exp(a_0 - b_0 \cdot 114.44)}{1 + \exp(a_0 - b_0 \cdot 114.44)}$ . When solving the mathematical system for parameters  $a_0$  and  $b_0$ , values of 3.12 and 0.0465, respectively, were obtained (Fig. 8). A maximum travel time of 225 minutes will be applied to the travel time calculations, since the impedance function will be nearly zero.

Lastly, a weighting factor will be included for the four different time periods: weekend and weekday morning and evening. The weighting factors are based on people's preferred moments for visiting museums, which are: weekday (34.05%), weekend (24.55%), other (i.e. holidays; 8.14%) and no preference (33.25%). Holidays are not included in the timeframes, and the people with 'no preference' are equally distributed over weekend visitors and weekday visitors. This means that weekday has a general preference of 58.10% compared to 41.90% for weekends. Converting these values into weights per timeframe, weekday morning and weekday evening will both obtain a weight of 0.2905 (half of 58.10%), while weekend morning and weekend evening obtain a weight of 0.2095 (half of 41.90%). This concludes all the parameters needed for calculating accessibility to museums.

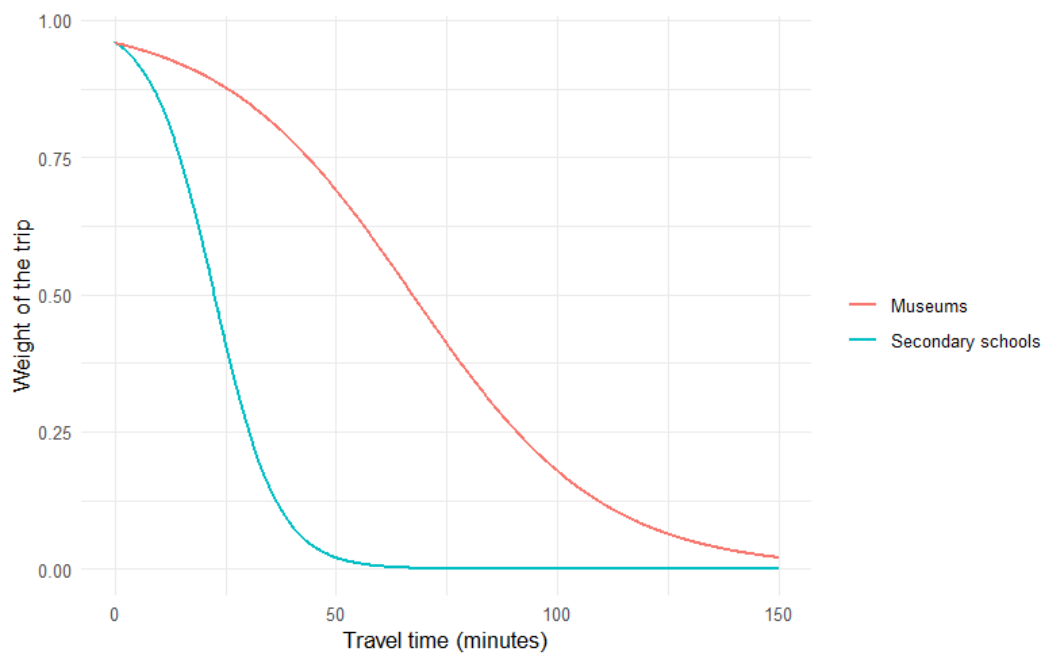


Figure 8: Calibrated impedance functions for secondary schools and museums

### 3.2.4 Mapping accessibility

The final part of the calculation procedure consists of mapping the findings in relation to the study's research question. The first research question encompasses where and how much accessibility changed on a Flanders-wide basis and how those changes compare for regions with different population densities. The second research question aims to identify how changes in service frequency, route configurations, stop locations, and timetables influence alterations in accessibility.

#### 3.2.4.1 Long-term accessibility change in Flanders and the BCR

For the first research question, the requirements are quite straightforward. Accessibility has to be calculated for 2016, 2023, 2024 and 2025, after which the percentual changes can be calculated. These include the changes between 2016-2023, 2023-2024, 2024-2025 and 2016-2025. The 2023-2024 and 2024-2025 changes will provide an idea of the impact of phases 2 and 3 of the Basisbereikbaarheid policy, while 2016-2023 provides information and context on the long-term changes preceding these phases. Finally, an overview of the changes is provided by calculating the difference between accessibility in 2016 and 2025 to assess cumulative changes.

The calculated accessibility maps and change maps will allow to assess reoccurring patterns if those are present, the magnitude of changes throughout Flanders and the BCR as well as where those changes are mainly located. Additionally, the changes seen in the change maps can also be partly contextualised with media articles and information on the implementation of the new policy. The second part of this research question focuses on compare the magnitude of accessibility change with population density. Doing so allows to assess whether areas with different population densities are impacted by accessibility changes.

#### *3.2.4.2 Influence of public transit service alterations on accessibility*

Answering the second research question is less straightforward as it examines ‘why’ accessibility changed. Network alterations affect individual trips, and those trip-level effects in turn drive accessibility outcomes. This intermediate layer of the impact of service changes on trips is often underexplored. Therefore, this part of the study examines those intermediate outcomes together with the root causes (public transport network changes) to understand the accessibility change. The analysis focuses on four aspects: network frequency, network configuration, mode-specific travel-time components (walking, waiting, in-vehicle), and variation in travel times throughout the day. As this is not feasible for all of Flanders, two case studies are used to illustrate the value of investigating these intermediate effects.

While any location in the study area could serve as a case, several criteria ensure that the two cases are distinct. The case study areas must be far enough apart to capture network changes in different regions. Each case must show meaningful variation in accessibility over time and within the area itself. Priority will also be given to more rural areas rather than city centres. Both because the current analysis is too coarse for a metropolitan case study and because rural areas typically have fewer lines and stops, making it easier to disentangle service changes. Finally, although both cases should be rural, they must differ in population density to reflect different degrees of rurality.

The approach consists of two steps. First, GTFS data are used to visualise public transport lines in and near each case study, together with transit stops and their hourly frequencies, for each of the four years. This allows direct comparison between network/frequency alterations and the accessibility changes calculated earlier. Secondly, average travel times have to be computed by mode and time of day. To obtain the modal travel times, trips must be recalculated in greater detail than for the first research question, which substantially increases computation. To preserve comparability across years and across hexagons, the number of amenity-locations used in the calculations is held constant for the case study home-location and set equal to the smallest number of amenities reached at

least once in any year. Since “at least once” can include trips with no valid connection, the maximum one-way travel time is increased from 75 minutes to 120 minutes for secondary schools to maintain most connections. For museums, instead of raising the previously used 225-minute maximum to a higher and more unpractical travel time threshold, only museums that are reachable at least 50% of time are retained. This avoids unrealistic trip durations and limits computation time. These choices can introduce some inconsistencies in the results.

## 4 Results and discussion: On the road

The findings for the accessibility analysis of schools and museums in Flanders and the Brussels-Capital Region (BCR) are presented and discussed per research question. First, we examine *how and to what extent local accessibility to secondary schools and regional accessibility to museums evolved across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025, and how these trajectories differ between high-density and low-density areas?* To do so, the absolute accessibility maps for the base year (2016) are discussed alongside the percentage change maps for 2016–2023, 2023–2024, 2024–2025, and 2016–2025, followed by a comparison of accessibility change across population-density brackets. Secondly, we investigate *how changes in service frequency, route configurations, stop locations and timetables across each phase of the Basisbereikbaarheid rollout (phases 0–3) and cumulatively between 2016 and 2025 have driven the observed shifts in public transport accessibility?* This is addressed through two case study areas that experienced substantial network changes. For each case, the evolution of the aggregated bus network between 2016 and 2025 is documented, including information on the stop locations and bus frequency. These changes are mapped for the same dates used above to contextualise the accessibility results. Additionally, the effects of the transit network changes on the travel time components (walking, waiting and in-vehicle) and average travel times throughout the day are analysed. Together, these steps clarify not only where and by how much accessibility changed, but also how specific service alterations translated into comparative travel time for residents of the case study areas.

When interpreting the results, it is essential to recall how accessibility is calculated in this research. A weighted cumulative opportunity (gravity) measure to secondary schools and museums is used. Although this approach produces absolute accessibility values, they are difficult to interpret directly. They can be understood as the number of opportunities that can be effectively reached or ‘effective opportunities’, but remain best used comparatively (Geurs & van Wee, 2004; Levinson & King, 2020). Accordingly, (changes in) accessibility will be described using relative terminology such as “high(er)/low(er)”, or “better/worse”. Non-comparative terms as “good/bad” will be avoided as neither the ‘Basisbereikbaarheid’ policy nor the Flemish government has defined a clearly quantifiable accessibility threshold for benchmarking (Vlaamse Overheid, 2025). Additionally, when reading the results and discussion, it is also important to keep in mind the mechanisms by which accessibility can change in this research. This analysis solely relies on GTFS data to estimate accessibility changes, which exclusively vary due to alterations in the public transit system. Finally, note that the calculated accessibility values rely solely on GTFS data. Accessibility, therefore,

varies only with scheduled public-transport changes; service frequency, route configuration, the number of routes serving an area, and the location/number of stops.

## 4.1 Long-term accessibility change in Flanders and the BCR

### 4.1.1 Accessibility to secondary schools

Figure 9 portrays local accessibility with secondary schools as a proxy for March 2016. As expected, more densely populated regions obtained higher accessibility values, with major transit corridors between them clearly visible. The largest values are concentrated within the Flemish Metropolitan Core Area (MCA). Outside the MCA, smaller and more dispersed cities form pockets of higher accessibility separated by larger low-accessibility zones. The low values near the border can be partly attributed to the exclusion of cross-border schools in Wallonia, the Netherlands and France. The study assumes that most students in Flanders and the BCR attend school in these regions, so clear border effects appear along the Flemish boundary. While low accessibility areas (accessibility  $< 0.5$ ) mainly correspond with sparsely populated areas, they still account for a quarter of the secondary school population. On the other side of the spectrum, close to 48% of people aged 10-19 live in areas with an accessibility of higher than 2. The remaining quarter experiences medium-level accessibility and can typically be found along main transit corridors between larger towns and on the edges of high-accessibility urban cores.

To translate “low” and “high” accessibility into travel-time terms, the average travel times to and from the three nearest secondary schools can be plotted (Fig. 10). As accessibility increases, mean travel times fall in a pattern consistent with a reciprocal power function ( $f(x) = \frac{1}{x^a}$ ). For hexagons with accessibility 0.25, mean times are 43, 49, and 51 minutes to the first, second, and third nearest schools, respectively. This drops significantly for hexagons with an accessibility of 0.75, who travel on average 31, 41 and 46 minutes to the three nearest schools. The reductions taper as accessibility rises further: at 2.5, mean times are 19, 28, and 33 minutes. In the highest-accessibility locations such as the centres of Ghent, Antwerp, and Brussels, mean travel times to the three closest schools are generally between 5 and 15 minutes.

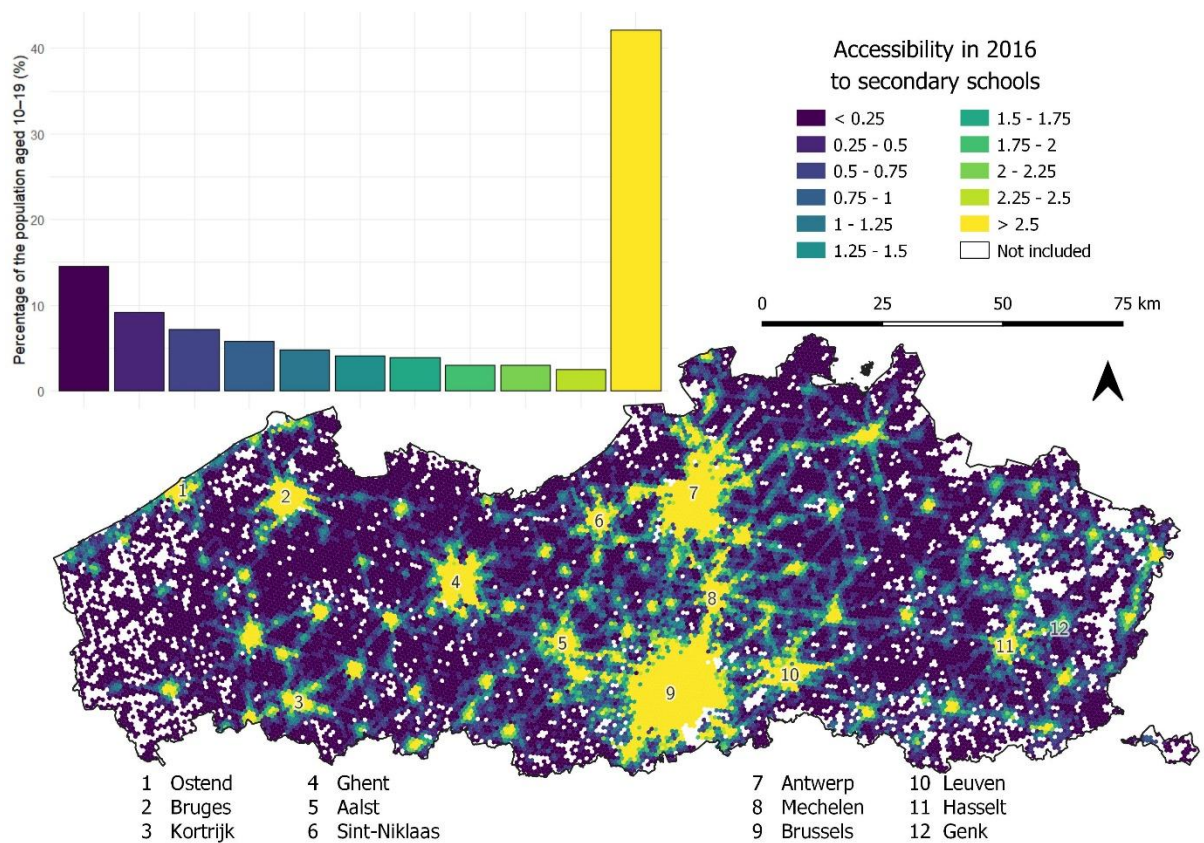


Figure 9: Accessibility to secondary schools in Flanders and the BCR in March 2016. The histogram shows the percentage

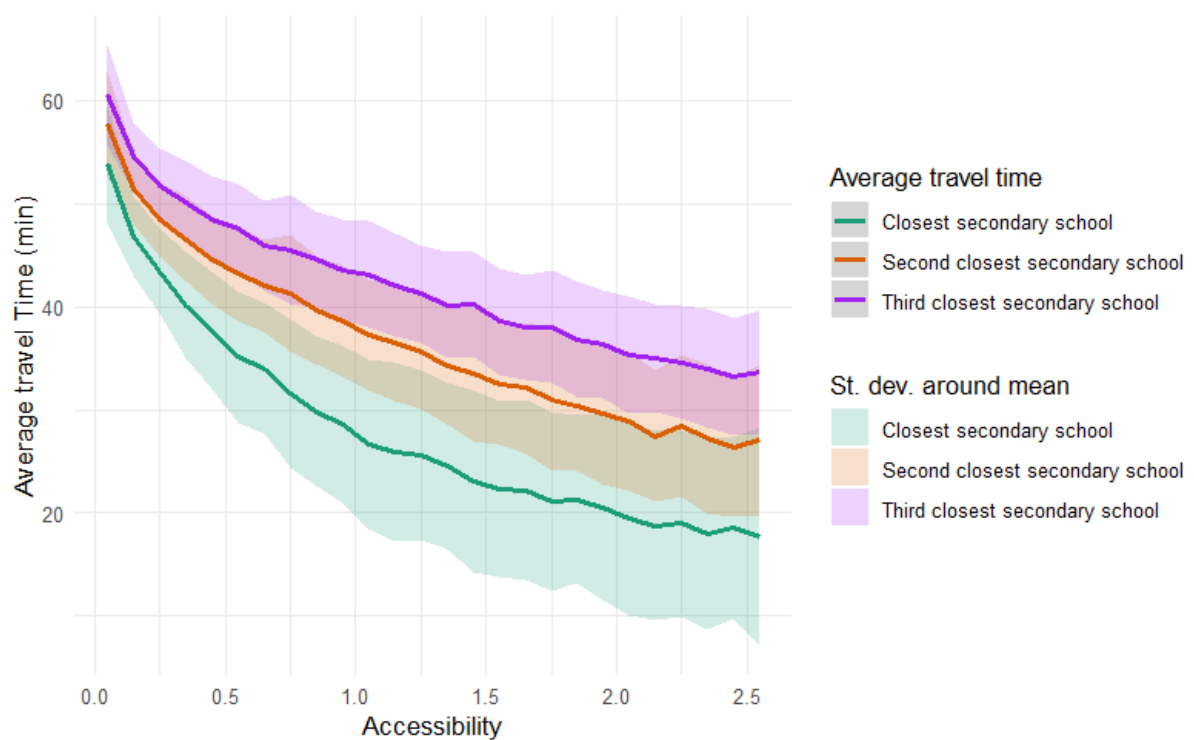


Figure 10: Average travel time to/from the three closest secondary schools compared to a hexagon's accessibility level

The percentage change in accessibility between March 2016 and December 2023 is portrayed in Figure 11. At this point, the first two phases (phase 0 and phase 1) of the Basisbereikbaarheid policy were already in effect since January and July 2023, respectively. Phase 0 introduced several “quick wins”, while phase 1 covered a mixture of 100 small to large modifications to the kernnet (core network), and aanvullend net (complementary network) (Rekenhof, 2024; Vlaams Parlement, 2023; Vlaamse Overheid, 2025). Additionally, the change map also captures the changes between March 2016 and December 2022, before the rollout of phases 0 and 1.

Overall, changes are spatially heterogeneous. Larger cities experienced relatively lower relative changes compared to their surrounding areas, likely due to the more robust transit systems. The most significant declines are observed in northern Flanders, the south of Limburg and the area around Ghent. Gains are mainly concentrated in northern Limburg, between Leuven and Brussels, south of Sint-Niklaas and in western Flanders, especially between Kortrijk and Bruges. Notably, regions experiencing strong relative change, tend to be the more rural areas with a low 2016 baseline accessibility, where even slight differences in the transit network can yield large percentual changes. The histogram confirms this trend as close to 60% of school-aged individuals experienced relatively little change ( $\pm 10\%$ ), although declines are more prevalent. Similarly, 23% of students experienced a medium-level (10-30%) decline in accessibility, compared to 6% who obtained better accessibility in 2023. For changes larger than 30%, the shares of students experiencing a strong decline is 8% versus 5% with a strong gain. These findings align with statements by the Court of Audit (Rekenhof), which reported lines operated in reduced form; lower frequency or shorter routes after phase 1 due to budget constraints or to avoid overlap with future alterations (Rekenhof, 2024).

Attribution of these changes remains challenging. While the phase 0 and 1 implementations likely contributed to the observed declines, it is not possible to cleanly separate their effects from pre-2023 adjustments as GTFS data immediately prior to the 2023 changes were not publicly available. This difficulty is compounded by the lack of exhaustive documentation of the phase-by-phase network alterations by De Lijn (Rekenhof, 2024).

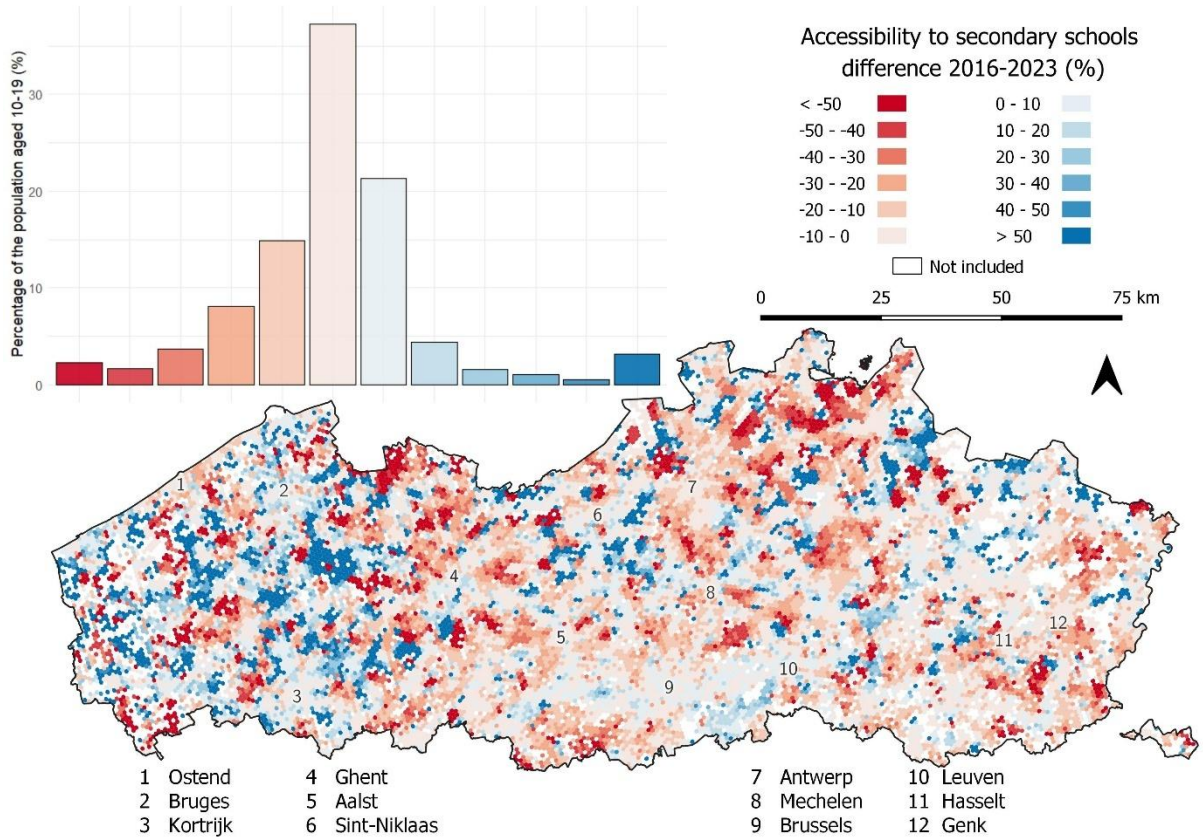


Figure 11: Change in accessibility to secondary schools in Flanders and the BCR between March 2016 and December 2023. The histogram shows the percentage people aged 10-19 in each category.

Figure 12 presents the changes between December 2023 and March 2024, coinciding with the implementation of second phase of the 'Basisbereikbaarheid' policy, described by the media as the largest reform made by 'De Lijn' (VRT NWS, 2024a). Significant changes to bus routes and stops took place and roughly the entire rollout of the 'tailored transit' (Vervoer op maat) was implemented (Rekenhof, 2024). Interestingly, the changes, implemented on January 6<sup>th</sup>, 2024 and the updates made afterwards did not result in strong alterations in the level of accessibility compared to December 2023. Approximately seven out of ten people aged 10 to 19 saw changes ranging within  $\pm 10\%$ . Areas with limited change in accessibility can mainly be found along Antwerp-Brussels corridor and throughout the province of Flemish Brabant. Decreases in accessibility exceeding 10% comprised 13% of the youth and are mainly present around northern and eastern Limburg, and western Flanders, especially the strip of hexagons just south of the coast. The 16% who strongly benefitted from the changes, mainly live in southern Limburg, east of Leuven, and the more rural areas in the province of Antwerp, East Flanders and West Flanders. The histogram reinforces that the areas experiencing strong changes are mostly rural areas, as most people only experience limited alterations to accessibility. Overall, compared to the changes between 2016 and 2023, these changes are relatively moderate, contrasting with the public and political backlash (NWS, 2025). Factors that might contribute to this disparity are the

media's emphasis on the removal of 3200 bus stops as well as teething problems of the phase's implementation such as delays, (unexpected) bus cancellations and other user experience factors that drive dissatisfaction and are often filed as complaints to the public transit services (VRT NWS, 2024d).

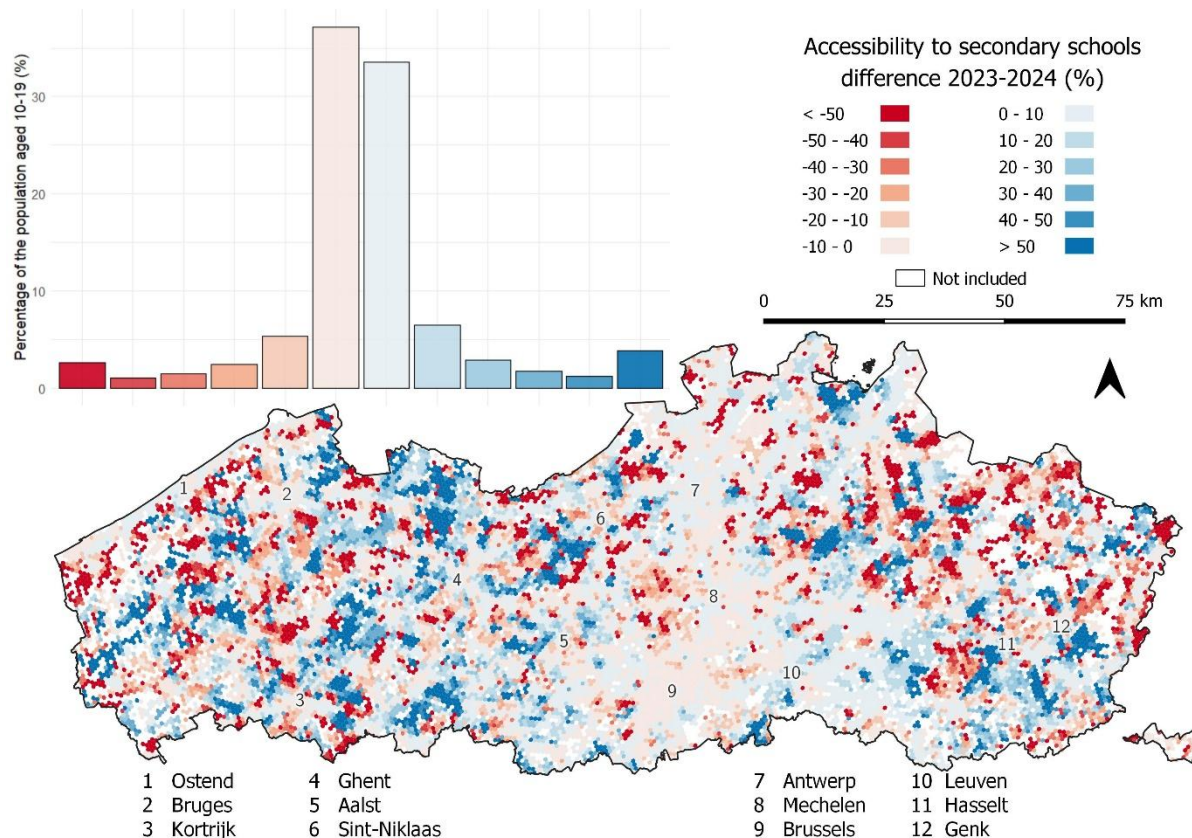


Figure 12: Change in accessibility to secondary schools in Flanders and the BCR between December 2023 and March 2024. The histogram shows the percentage people aged 10-19 in each category.

The implementation of phase 3 occurred in January 2025, and Figure 13 shows the percentual changes between March 2024 and March 2025. Approximately seven out of ten people aged 10 to 19 saw changes ranging within  $\pm 10\%$ . Areas with limited decreases in accessibility can mainly be found west of the Antwerp-Brussels corridor, and in western Flanders, mainly along the transit corridors between the larger cities (Ostend, Bruges, Kortrijk and Ghent). On the other side of the spectrum, it is mainly Limburg experiencing increases in accessibility (apart from the areas around Genk and Hasselt), as well as the more rural areas between Ghent, Kortrijk and Bruges. Regions with decreases in accessibility exceeding 10% comprised 22% of the youth and can mainly be found around Mechelen, Sint-Niklaas, Aalst, the province of Flemish Brabant, which remained relatively untouched in the previous phase, and the eastern part of the province of Antwerp. The 9% who strongly benefited from the changes can also be found in the same general area where strong decreases are present, as well as in southwestern Flanders. As mentioned earlier, these areas

are mainly more rural areas with less robust public transit services, meaning that even limited alterations to the network can already significantly affect accessibility.

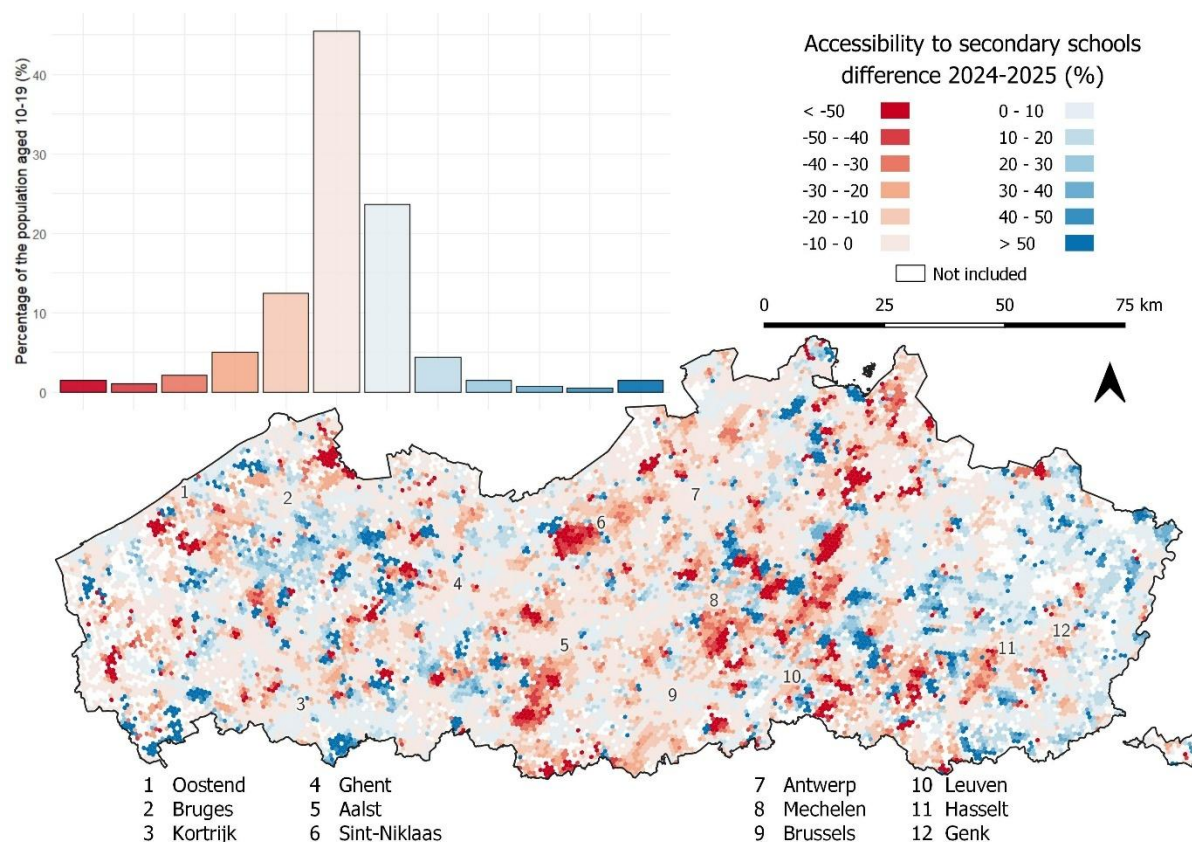


Figure 13: Change in accessibility to secondary schools in Flanders and the BCR between March 2024 and March 2025. The histogram shows the percentage people aged 10-19 in each category.

While these change maps provide a valuable insight into how accessibility to secondary schools changed after the implementation of each phase, it is also necessary to keep an overview of the cumulative accessibility change between March 2016 and March 2025 to gain an overview of the overall changes (Figure 14). Areas with the largest decrease are predominant in the Flemish MCA, the province of Antwerp and large parts of Flemish Brabant. On the other hand, areas with positive changes are mainly present in the more rural areas of the provinces of Limburg, East and West Flanders. The histogram clearly shows a significant asymmetry between gains and losses, with most students seeing a decrease in accessibility. Seven out of ten students experienced small to major decreases in accessibility, contrasting sharply with the other 30% who benefited from the changes. While the strongest variations in accessibility often occur in more rural areas, even hexagons located in cities and their peripheries can obtain strong decreases in accessibility, which is noteworthy given the presence of more robust public transport services. Taken together, the

results clearly indicate a negative net effect on long-term accessibility, which was seemingly amplified by phases 2 and 3 of the new policy.

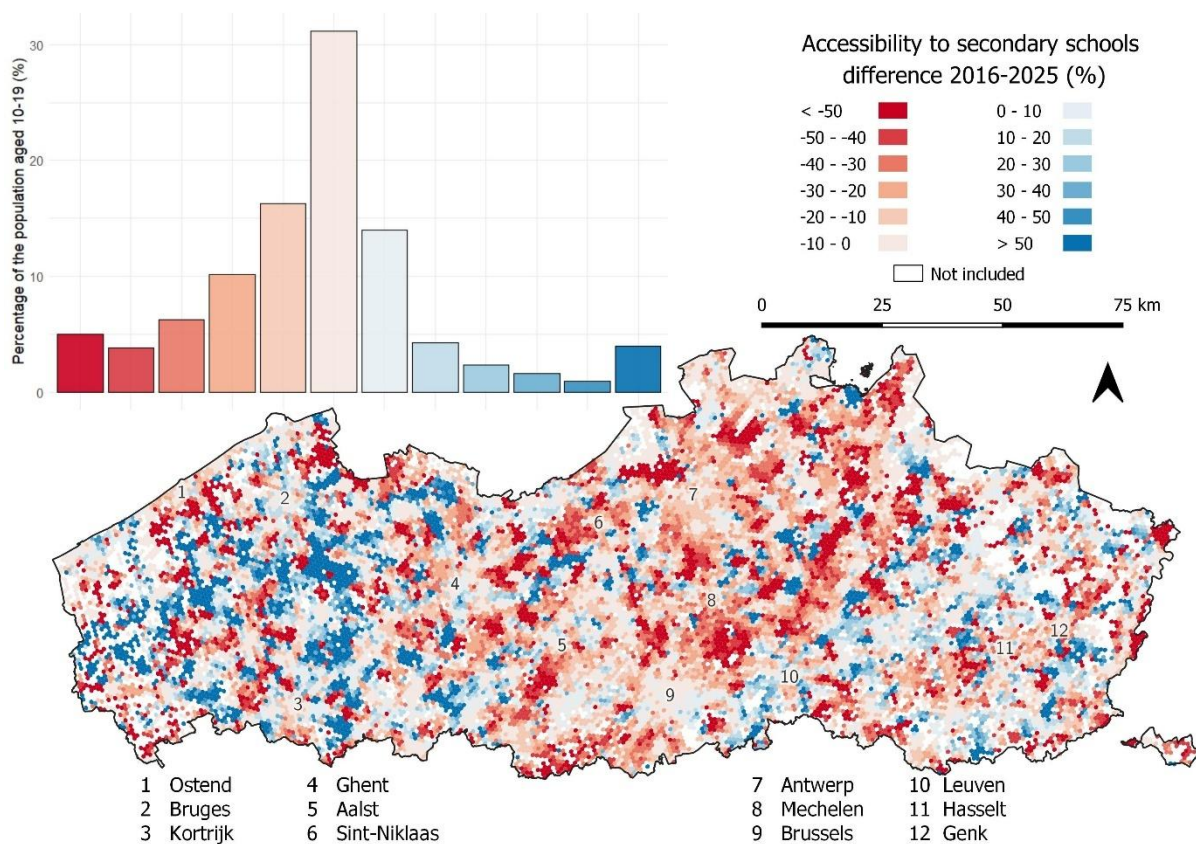


Figure 14: Change in accessibility to secondary schools in Flanders and the BCR between March 2016 and March 2025. The histogram shows the percentage people aged 10-19 in each category.

Beyond identifying where in Flanders and the BCR changes occurred, it is important to assess for whom these changes are most impactful. While a detailed socio-economic analysis is beyond the scope of this research, a comparison of accessibility changes across areas with different population density is provided as a simple proxy for estimating urban-rural discrepancies in accessibility change. Figure 15 portrays the average change in accessibility in each population density bracket. Before discussing the results, one has to keep in mind that the total population in each bracket is roughly the same, meaning there will be more hexagons present in low-density brackets.

Between 2016 and 2023, most regions experienced decreases of 5%, except for the highest and lowest density brackets, whose decreases were lower. However, hexagons with lower population densities did experience more variability in their accessibility changes. A different dynamic is notable for changes observed between 2023 and 2024. Most areas experienced a slight positive change, while the most densely populated urban areas experienced a decline. Even though there is a slight improvement for most population density brackets,

the magnitude of the increase is significantly lower than the magnitude of the decline between 2016 and 2023. After implementing the third phase in January 2025, the 2016-2023 change dynamic re-emerged. On average, all brackets experienced a decline again, which was least pronounced for the highest and the lowest density brackets. What differs in 2024-2025 is the smaller spread of the standard deviation and the marginally smaller percentual decreases. The cumulative change between 2016 and 2025 largely mirrors the 2016-2023 and 2024-2025 patterns. Accessibility declined across every bracket, with the highest variation in the low-density brackets, which reduces with increasing population density. There does not seem to be a strong difference in average change between low -and high-density populated hexagons, but the standard deviations do suggest that the lower-density populated areas are more sensitive to the changes in accessibility, both positively and negatively. Overall, there is a clear long-term decrease in local accessibility of around 8% on average in most brackets, which seems to contrast with the government's goal of making (secondary) schools fluently accessible for everyone (Vlaamse Overheid, 2025).

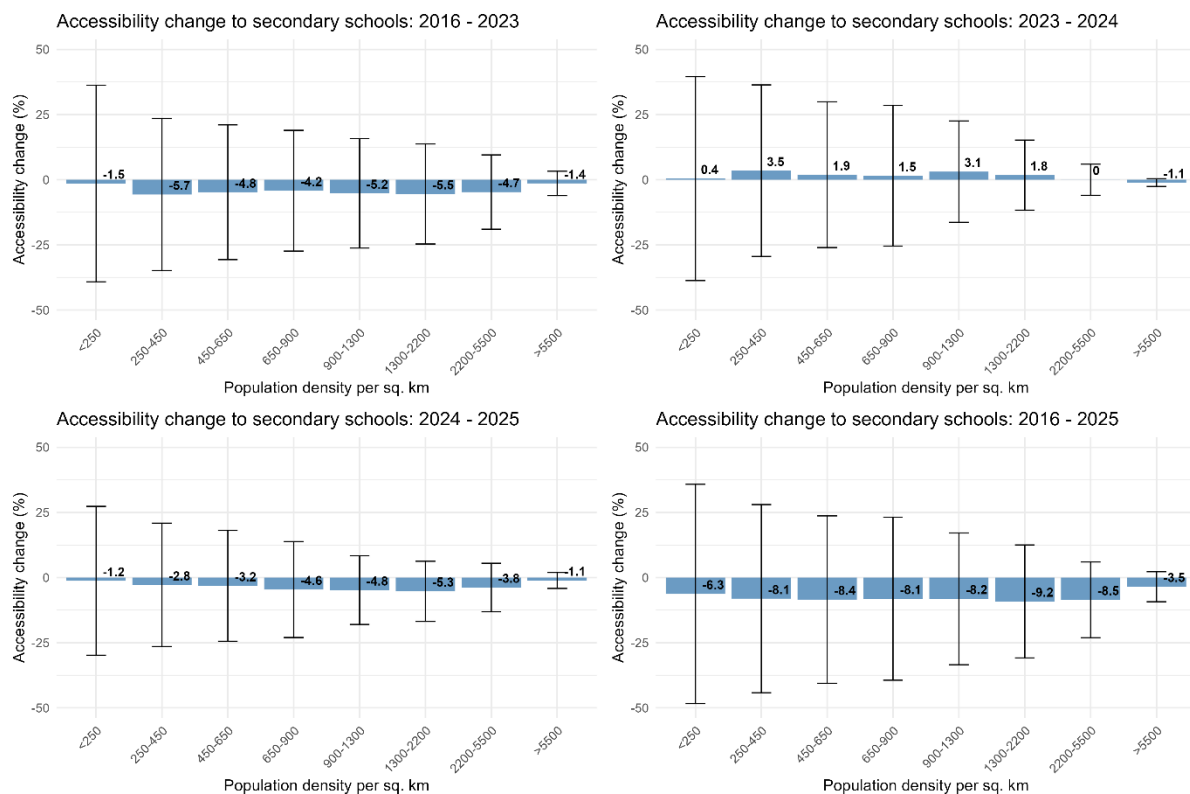


Figure 15: Accessibility change for secondary schools per population density bracket between 2016-2023 (top left), 2023-2024 (top right), 2024-2025 (bottom left) and 2016-2025 (bottom right) and their variation indicated by the standard deviation around the mean. All population density brackets represent between 950,000 and 1,000,000 people

#### 4.1.2 Accessibility to museums

In this second part, accessibility to museums and its change between 2016 and 2025 are calculated as a proxy for regional-scale accessibility dynamics. There are three main differences in the accessibility calculations for secondary schools. Firstly, there are 568 museums accounted for in the calculations, which are mainly present in larger cities, compared to 772 secondary schools (Fig. 7). Secondly, the maximum travel time increased from 75 to 225 minutes, resulting in a more gradual decline of the impedance function, and thus higher weights for locations further away. Thirdly, the timeframes for which accessibility will be computed are also different. Instead of secondary school timeframes, museum travel times are calculated for 08:00-11:00 and 18:00-21:00 on both weekdays (Monday as proxy) and weekends (Sunday as proxy).

Figure 16 presents the accessibility to museums in 2016. While the general patterns are similar to the secondary schools' accessibility map, there are some important differences. Cities have again the highest accessibility, but the top values are now more confined to the MCA, with the highest level of accessibility encompassing over a fifth of the population of Flanders and the BCR. The major transit corridors between cities and larger towns are also still clearly visible, but are now wider and show a gradient from the centre of the corridor to its edges, which is a result of the slower decay of the impedance function. Another similarity to the secondary school accessibility map is that low-accessibility areas ( $<10$ ) still account for a large percentage (20%) of the population. What is not visible on the accessibility map for secondary schools is the clear definition of train stations on the map as high-accessibility dots. These are clearly visible across the entire map, for example: between Ghent, Bruges and Kortrijk, between Ghent, Antwerp and Brussels, north of Hasselt and east of Mechelen. This clearly illustrates the increased importance of trains and long-range public transportation in general, yielding a different dynamic compared to local accessibility, which is consistent with the findings by Verachtert et al. (2023).

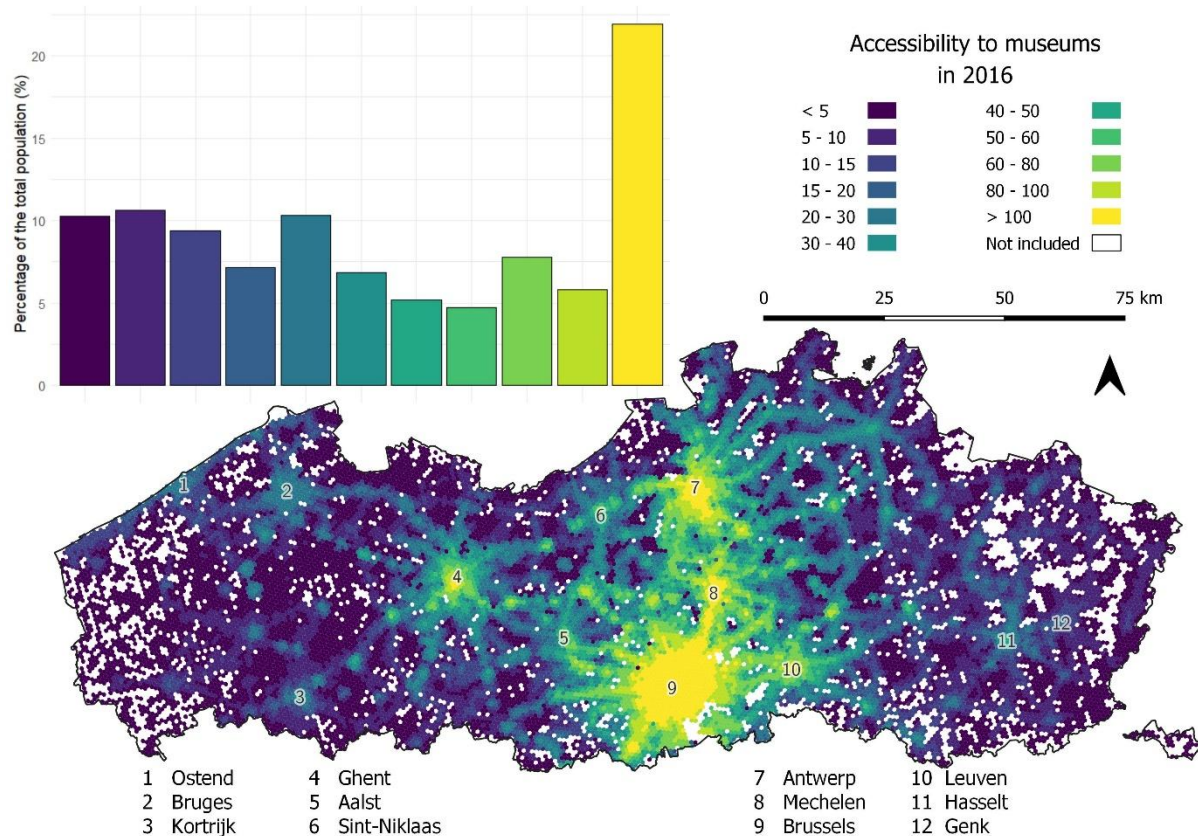


Figure 16: Accessibility to museums in Flanders and the BCR in March 2016. The histogram shows the percentage of total population in each category.

Figure 17 shows the change in accessibility to museums between 2016 and 2023. There is clearly a strong trend towards accessibility increase as most areas in Flanders and the BCR experience improvements. Areas with improvements are prominent throughout the whole of Flanders, except for the region northwest of Ghent, the surroundings of Bruges and the northern part of the province of Antwerp. Overall, areas where accessibility increased encompassed 71% of the total population, although most obtained moderate improvements (0-10%). On the other hand, 29% of the population experienced decreasing accessibility, with again a large majority only seeing minor declines. These results differ significantly from the findings for local accessibility and show the opposite dynamic. While 70% of the obtained better regional accessibility, only 30% obtained better local accessibility. Additionally, spatial patterns of the change also show some distinct differences. Areas experiencing a decrease for regional accessibility also show this pattern for local accessibility, albeit with more intra-area variation. For most other regions in Flanders and Brussels, the trend changes from predominantly negative to predominantly positive change, especially clearly in Limburg and (south)western Flanders. Also noteworthy is the relatively homogeneous and aggregated nature of regional accessibility change patterns. For local accessibility change, a more heterogeneous spatial pattern was noticeable, as proximity to the opportunity and local public transit were more important.

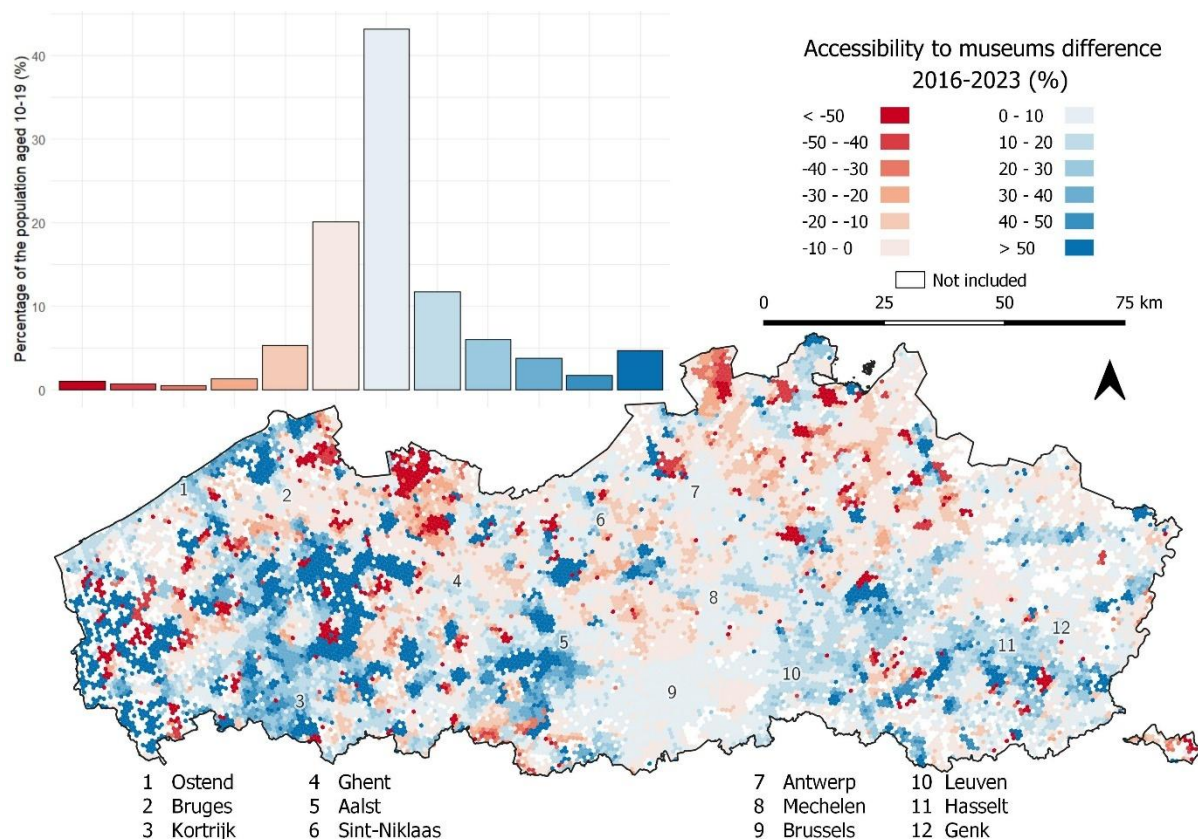


Figure 17: Change in accessibility to museums in Flanders and the BCR between March 2016 and December 2023. The histogram shows the percentage of the total population in each category.

The accessibility change between December 2023 and March 2024 is more balanced between winners and losers (Fig. 18). With 60% of people experiencing gains mainly located throughout Limburg and the region between Mechelen, Brussels and Leuven. Additionally, cities and some rural areas in the provinces of West and East Flanders also saw accessibility gain; however, the patterns there are more complex, as hexagons with strong accessibility gains are frequently alternated with hexagons with severe losses. This pattern can also be observed in the province of Limburg, though to a lesser extent and with the most areas experiencing losses confined to the border with Wallonia and the Netherlands. Lastly, the northern part of the province of Antwerp followed its trend of decreasing accessibility, although most changes remained relatively limited. The patterns of regional accessibility change between 2023 and 2024 are more alike their local accessibility counterpart, compared to previous change maps. Areas with limited change in Flemish Brabant and between Brussels and Antwerp are present in both maps, as well as the heterogeneous patterns of accessibility change in Limburg and western Flanders, albeit to a more limited extent. Additionally, the regional accessibility change map for this period also shows a stronger presence of accessibility gains, especially in Limburg, West Flanders and the southeastern part of the province of Antwerp.

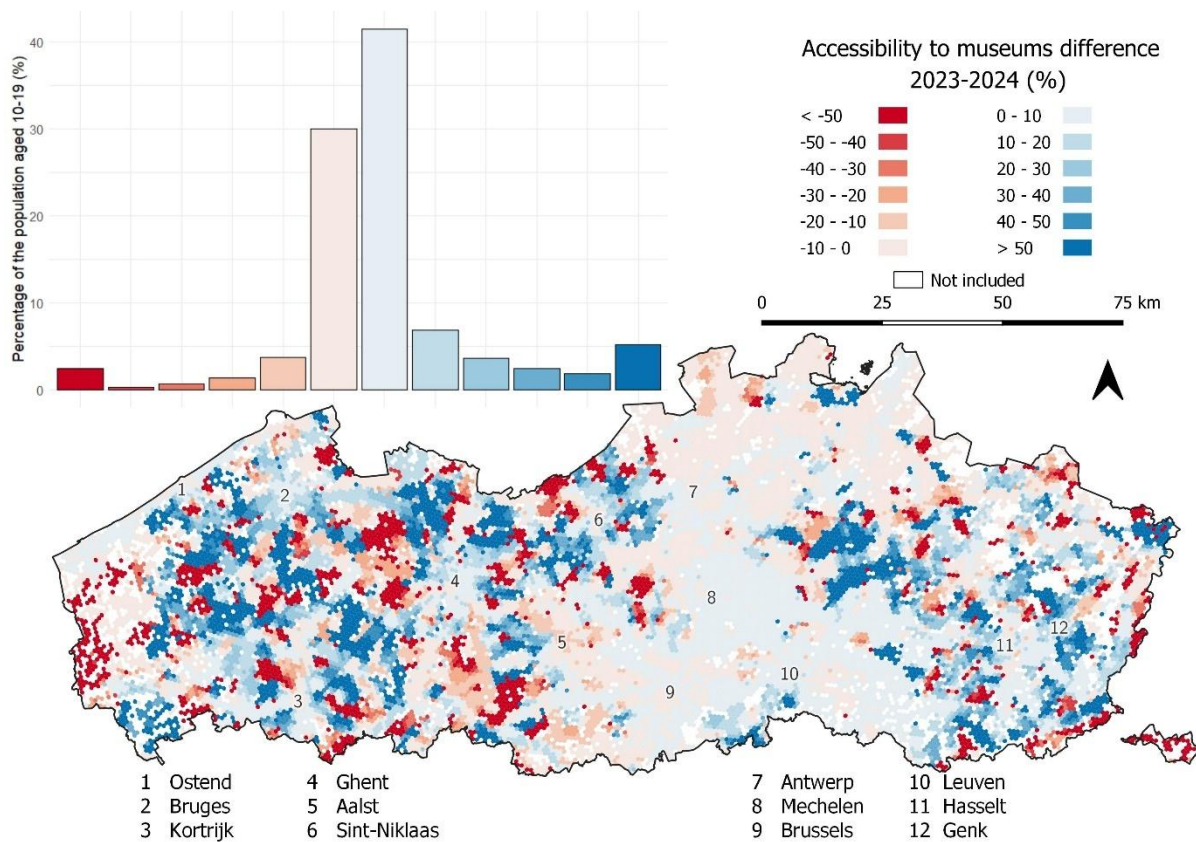


Figure 18: Change in accessibility to museums in Flanders and the BCR between December 2023 and March 2024. The histogram shows the percentage of the total population in each category.

The dynamic of mainly positive changes between 2016 and 2024 changed drastically between 2024 and 2025 (Fig. 19). Nearly every area experienced some degree of decline in accessibility, with the only major exception being the region around Ostend and Bruges. This dynamic also returns in the number of people seeing their accessibility reduced, with 85% of the total population experiencing some degree of decline. This is significantly more severe than the 70% seeing declines in local accessibility in the same period. The areas that are hit the hardest are south and east Limburg, the region around Sint-Niklaas and the southwestern Flanders. Even larger cities as Kortrijk, Sint-Niklaas, Hasselt and Genk experienced relatively strong degrees of decline, even though they have a more robust public transport system than their surrounding areas. While local accessibility also declined during this period, its severity and spatial extent were more limited. At the local scale, large parts of Limburg experienced increases in accessibility, and the declines in the western part of Flanders and the province of Antwerp were more limited. These findings are quite interesting, especially for Limburg, as there is a clear divergence between local and regional accessibility change.

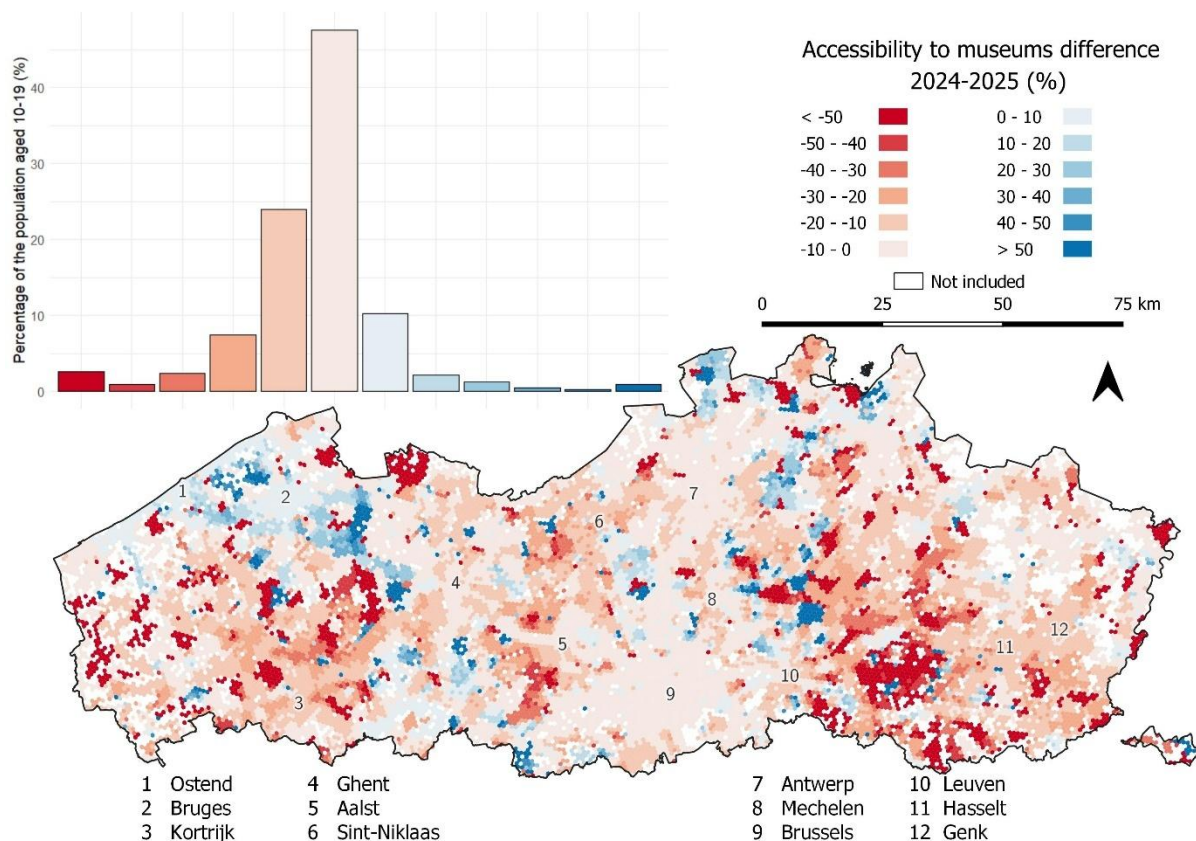


Figure 19: Change in accessibility to museums in Flanders and the BCR between March 2024 and March 2025. The histogram shows the percentage of the total population in each category.

When examining the long-term accessibility changes between 2016 and 2025 at the regional scale, the influence of the 2024-2025 period is still prominent (Fig. 20). Especially in the provinces of Antwerp and Flemish Brabant are the accessibility declines of 2024-2025 clearly visible. This is also the case in western Flanders and Limburg, as they overlap nicely with the areas of strong decline in 2024-2025. The impact of the 2024-2025 declines can also be seen in the histogram, with slightly under 60% of people seeing a decline, although more than half of those only experienced limited negative impacts. Other areas with a negative impact can mainly be found in the province of Antwerp and the eastern part of Flemish Brabant. In the western parts of Flanders, the areas with strong decreases are again often alternated by larger areas with strong increases. This dynamic can also be noted in the province of Limburg and Antwerp. While most people experienced a decrease, the population seeing increases often obtained larger increases relative to the population that saw a decrease. Compared with the 2016-2025 local accessibility change, the decline in regional accessibility is significantly less severe. This again clearly demonstrates that the impact of changes to the public transit system can have different effects at varying spatial scales and times of the day/week.

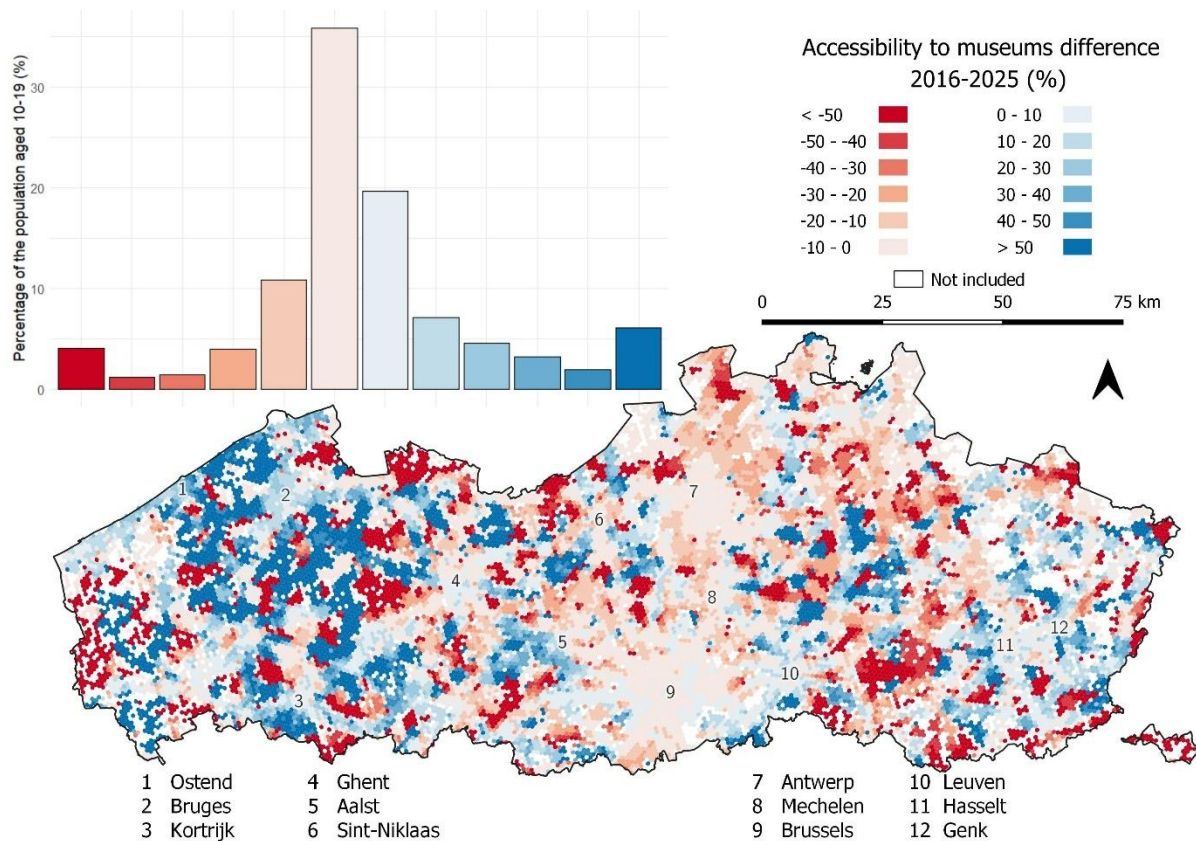


Figure 20: Change in accessibility to museums in Flanders and the BCR between March 2016 and March 2025. The histogram shows the percentage of the total population in each category.

To get an idea of who benefited from the public transit changes, the accessibility changes for different population density brackets can again be compared (Fig. 21). For the period 2016-2023, there was an increase of around 8% in all brackets, except for the highest population density bracket. Here, the standard deviation also declined with increasing population density as fewer hexagons are included in larger population density brackets, and those brackets generally have more robust public transit. For the 2016-2023 period, the results for local accessibility had the opposite dynamic, with a decrease in all categories. This changed for the period between 2023-2024, where both local and regional accessibility increased for almost all density brackets. However, the increase was significantly higher for regional accessibility, especially at lower population densities. Between 2024 and 2025, both regional and local accessibility saw decreases across all brackets, but declines were more severe at the regional scale. This is especially the case for more rural areas, which experienced a more-than-10% decrease. While this decline was also severe for other population density brackets, it clearly decreased with increasing population density. Lastly, the long-term accessibility changes between 2016 and 2025 for regional accessibility do show an average increase in accessibility for most population density brackets apart from

the lowest and highest densities. However, from the standard deviation, it becomes clear that the variation of these changes differs significantly from hexagon to hexagon. To illustrate, for all hexagons with a population density of 250 or lower, 68% experienced a change between -50% and +50%. Compared with local accessibility, the findings for the 2016-2025 period are quite the opposite, with local accessibility seeing an average decrease across all brackets, again portraying the different dynamics between local and regional accessibility.

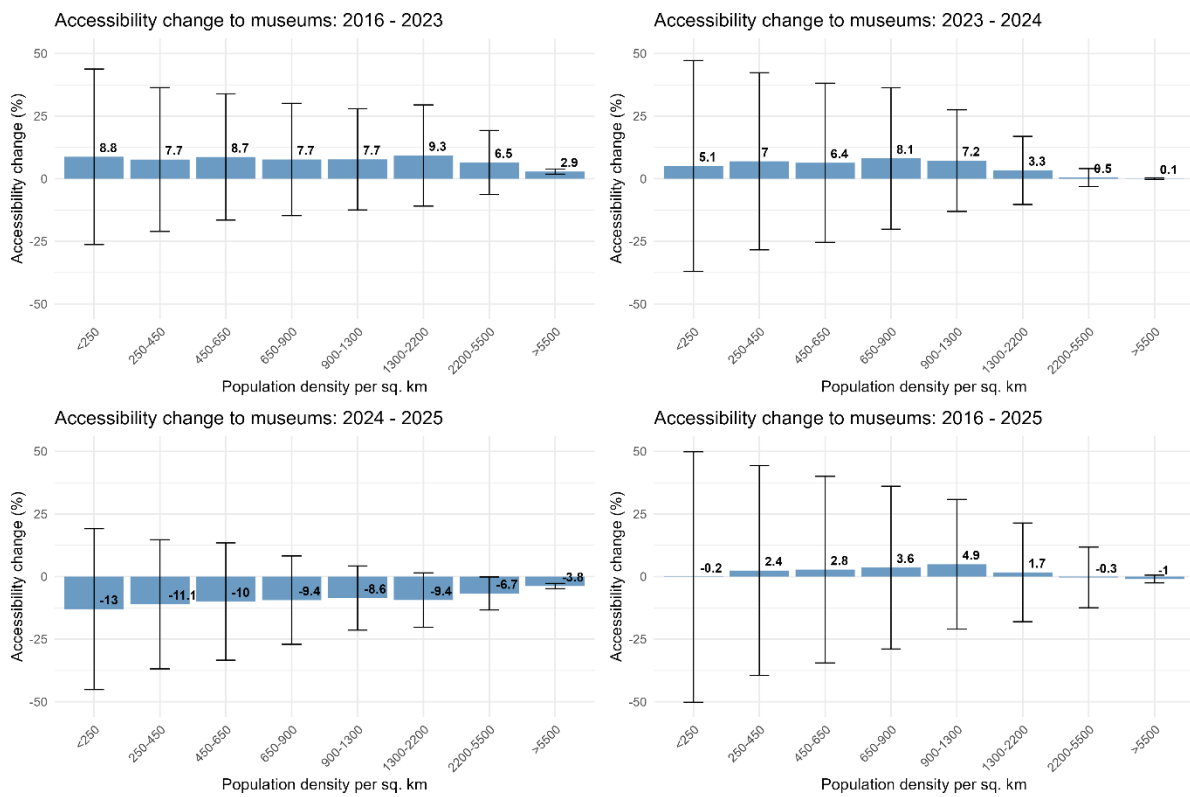


Figure 21: Accessibility change for museums per population density bracket between 2016-2023 (top left), 2023-2024 (top right), 2024-2025 (bottom left) and 2016-2025 (bottom right) and their variation indicated by the standard deviation around the mean. All population density brackets represent between 950,000 and 1,000,000 people

## 4.2 The influence of public transport alterations on accessibility

The accessibility maps and change maps for Flanders and the BCR provide a comprehensive overview of the accessibility to secondary schools and museums, and how it has evolved over the years. To complement these findings, the following case studies in Morkhoven and Pelt allow us to assess how alterations in the public transit network influence changes in local and regional accessibility. There are three main aspects to this: first, the alteration of frequencies, rerouted transit lines and modified bus stops. Secondly, when public transit changes influence accessibility, they also influence travel times. So, how do travel times per mode (waiting, walking and in-vehicle time) differ over the years? Lastly, are the transit changes more impactful at certain times of the day?

This analysis requires the examination of route frequency and configuration, and the contribution of travel modes to the overall travel time and accessibility. Performing such an analysis for Flanders and the BCR would be complex and computationally demanding. By selecting two case studies, a more manageable yet still meaningful analysis can be conducted. Morkhoven and Pelt were chosen as case studies as they are geographically distant and thus rely on different public transit lines, which might be affected differently. Both case studies represent more rural areas with a less dense public transit network compared to cities, facilitating the attribution of accessibility changes to specific network modifications. Lastly, these areas exhibit variation in accessibility levels over time, space, and scale (local vs. regional), making them suitable for a more detailed assessment of accessibility change.

Accessibility in this research considers both access from the home location to the opportunity and the other way around. For the case studies, however, I opted to only consider public transport services near the home location. While this will not provide a complete overview, it provides information on (changes in) the transit network that arguably have the largest influence on accessibility, being the changes close to home. Of course, one could argue that the public transit characteristics at the opportunity location are equally important. While they are certainly relevant, changes near the origin likely have a larger impact, as accessibility in this study is defined as a cumulative entity, where all reachable destinations within a given time threshold are considered. Consequently, modifications to the transit system near the home location affect more travel paths than those near a single opportunity location. This view can be visualised as a spider web. When travelling from the centre (home location) to multiple points on the web (opportunities), or the other way around, the inner threads (transit lines) will be used more often. Changes at a certain destination might influence some connections, while those at the centre will impact significantly more.

#### 4.2.1 Case study 1: Morkhoven

The first case study consists of an area of about 30 km<sup>2</sup> with three small villages, with a total of around 9,000 inhabitants, of which roughly 1,000 are students. It is a rural area located between the larger towns of Herentals and Heist-op-den-Berg, both of which have a railway station, offering access to other major cities in the region (Figure 22). In 2016, a total of 21 lines served the area, primarily oriented along a north-south or east-west direction. By 2023, this number had increased to 30 lines. However, most of these additions were only short-distance routes that did not substantially expand the spatial coverage of the network. Notable changes included the removal of the interprovincial line connecting the city of Antwerp to the province of Limburg and the introduction of an additional line to Lier. In 2024, the number of transit lines declined to 19. Most transit corridors were retained, although several routes in the northeast of the case study are no longer operated or have been changed. One of these changes is the service Leuven-Turnhout, which was split into two.

Between 2024 and 2025, some minor changes occurred in the west, with the removal of a direct line to Mechelen. More importantly, no route remains that fully traverses the north-south axis of the case study area. While discussing the decision-making behind all these changes is beyond the scope of this research, one exception is worth highlighting here. The bus line longer traverses the entire length of the case study area because of major roadworks in the centre of the village of Morkhoven, necessitating a detour (De Lijn, 2024; Gemeente Herentals, n.d.). While information on route alterations due to external circumstances (e.g. road works) is provided by De Lijn, detailed data on the network modifications per phase is not (Rekenhof, 2024). This limits the comparison of bus lines at different dates to general descriptive information, and it limits the understanding of the context in which accessibility changes occurred.

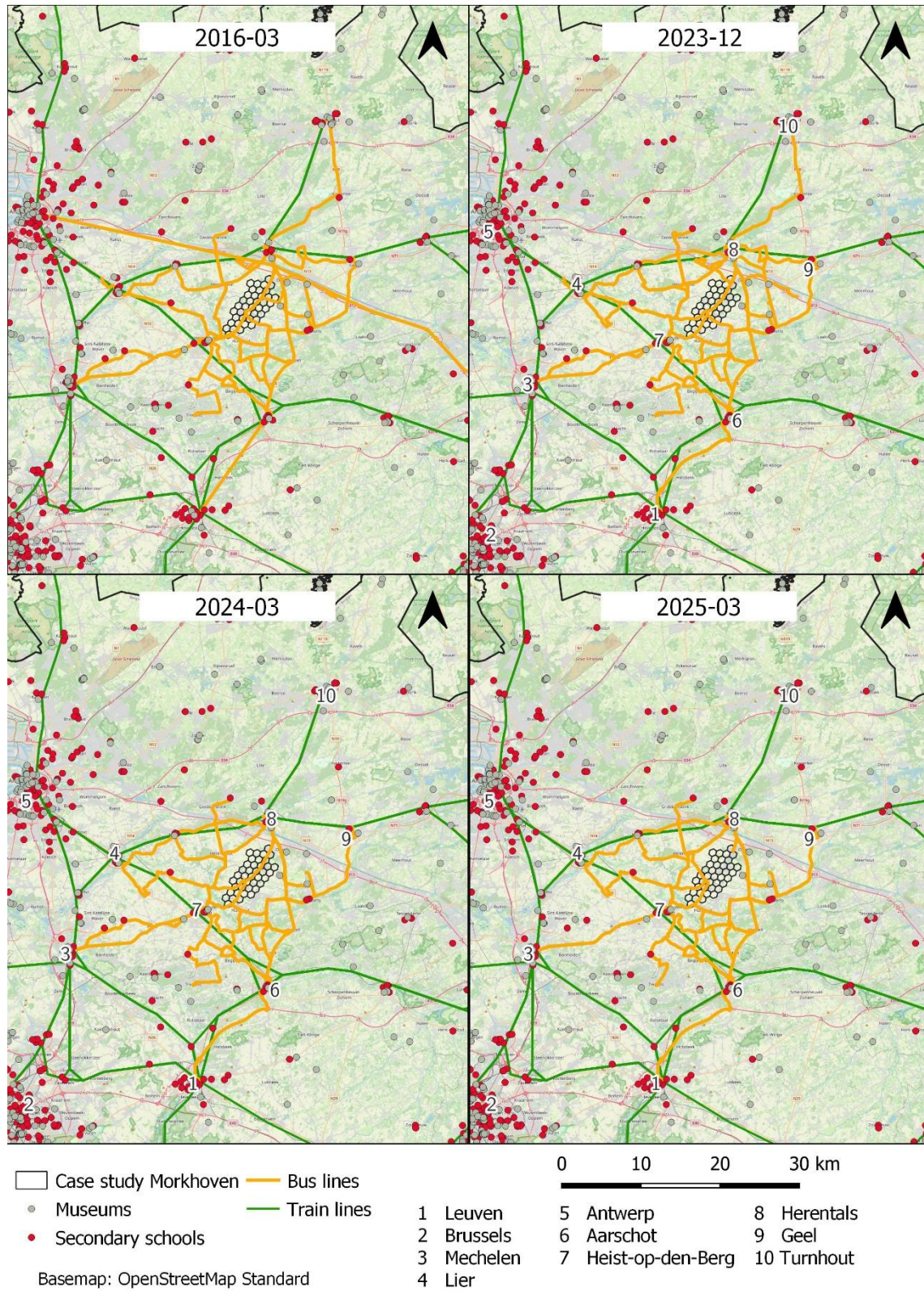


Figure 22: Overview of the bus lines and train lines that pass in the vicinity of the Morkhoven case study area for 2016, 2023, 2024 and 2025. Overview of the museums and secondary schools in the larger regions around Morkhoven.

#### 4.2.1.1 Accessibility to secondary schools

Before going over the accessibility changes in Morkhoven, the situation in March 2016 should be examined (Figure 23). The highest frequency of routes can be found along the three north-south axes to the east, west and in the centre of the case study area. Additionally, south of the area are also bus routes running with high combined frequencies in an east-west direction. While these frequencies provide a good idea of how often buses serve certain stops, they represent the combined frequency of buses from all routes serving that stop. Nonetheless, the accessibility values clearly align nicely with the central north-south bus line and the southern east-west bus lines. The other two high-frequency lines running north-south have notably less influence on the accessibility due to their relative distance from the case study area. Lastly, the two minor lines entering the case study area from the east clearly have a lower impact on accessibility of nearby hexagons compared to the high-frequency central bus line.

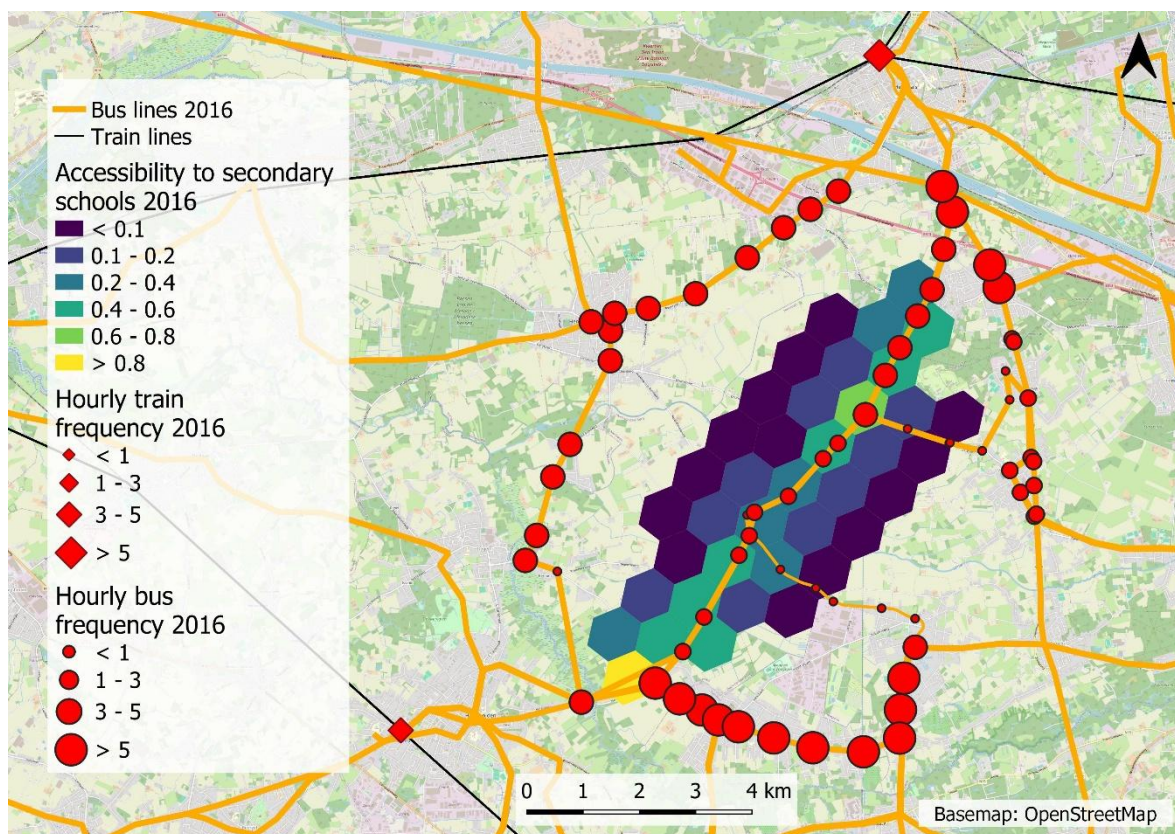


Figure 23: Accessibility in 2016 in the Morkhoven case study area and hourly bus frequency at bus stops within a range of 1500m of the case study area (red dots). The bus lines are depicted in orange.

Compared to 2016, the accessibility to secondary schools in 2023 dropped everywhere except in the southwest (Figure 24, top left). The increase in accessibility there can be explained by the implementation of an additional low-frequency bus line west of the area. This illustrates that low-frequency bus lines can certainly influence local accessibility, but to a lesser extent than high-frequency bus lines, as only four hexagons experienced improved accessibility. The main trend, however, is a relatively strong reduction of 20% to 40% in the north and a decline exceeding 40% in the south, corresponding nicely with the reduced hourly bus frequency. The steeper declines in the south also align nicely with the stronger reduction of bus frequencies in the south. Slight increases in frequency of neighbouring lines, especially in the south and west, seemingly did not mitigate the strong decline, implying that these lines only have a limited influence on the accessibility of the case study area.

The implementation of phase two of the 'Basisbereikbaarheid' policy brought significant changes to the bus routes and number of stops (Figure 24, top right). In 2024, the two smaller lines entering the case study area from the east were discontinued, and stops along the main central bus transit line were also put out of service. However, the remaining stops along this line did experience a strong increase in frequency, significantly improving accessibility across the entire area. Also contributing to the increase, but to a lesser scale, are the bus stops around the case study experiencing frequency increases. Reducing the number of stops along transit lines can theoretically have two main consequences. It might decrease bus travel times, but on the other hand, it could increase walking distances, potentially disproportionately affecting less-mobile users. Nonetheless, the potential negative effect of longer walking times on accessibility is outweighed by the factors positively influencing accessibility. However, accurately discerning whether faster bus travel times outweigh the potential negative impact of increased walking distance is not possible based on these findings alone.

In March 2025, the accessibility gains made the previous year are completely wiped out due to the aforementioned external circumstances (Figure 24, bottom left). As extensive road works in the centre of Morkhoven commenced, buses originally travelling along the central north-south corridor were forced to take a detour. As a result, public transit services were withdrawn from the area and bus stops were no longer served, leading to a sharp decline in accessibility across much of the case study area. This could not be mitigated by the increase in frequency of the lines in the west, which now accommodate the diverted buses. Only in the southwest were the declines slightly mitigated due to the proximity of other high-frequency bus stops and the increase in buses entering the case study area from the west. Nevertheless, these mitigations were not nearly enough to compensate for the high losses

suffered elsewhere. This shows that the influence of the central line alone explains a very large proportion of the achieved accessibility in the area.

The cumulative accessibility change from 2016 to 2025 is shown in Figure 24 (bottom right). The overall trend indicates a strong decline as the services along the central north-south axis were removed between 2024 and 2025. The findings reinforce that the central north-south corridor is critical to local accessibility. Hexagons in the northeastern corner of the case study area experienced more moderate changes, likely due to their proximity to high-frequency stops in the east. Similarly, hexagons in the far south also retained more of their original accessibility, thanks to the relatively proximity of the remaining high-frequency stops. The only area experiencing net positive changes is located in the southwest, where a new route was added between 2016 and 2023, and where bus frequency increased in 2025. However, the lack of spatial coverage limits the route's positive effect.

While changes in route configurations and stop frequencies have a clear influence on accessibility, the impact of these changes on individual modes is harder to assess. Therefore, the average segment duration of trips (walking, waiting, in-vehicle and total) and their evolution between 2016 and 2025 are calculated. The travel times of these segments are calculated per hexagon to all schools reached at least once in Flanders-wide accessibility calculations and weighted by each trip's accessibility values. The resulting Figure represents an accessibility-weighted average travel time per home hexagon and per mode (Fig. 25). The travel times are best interpreted comparatively.

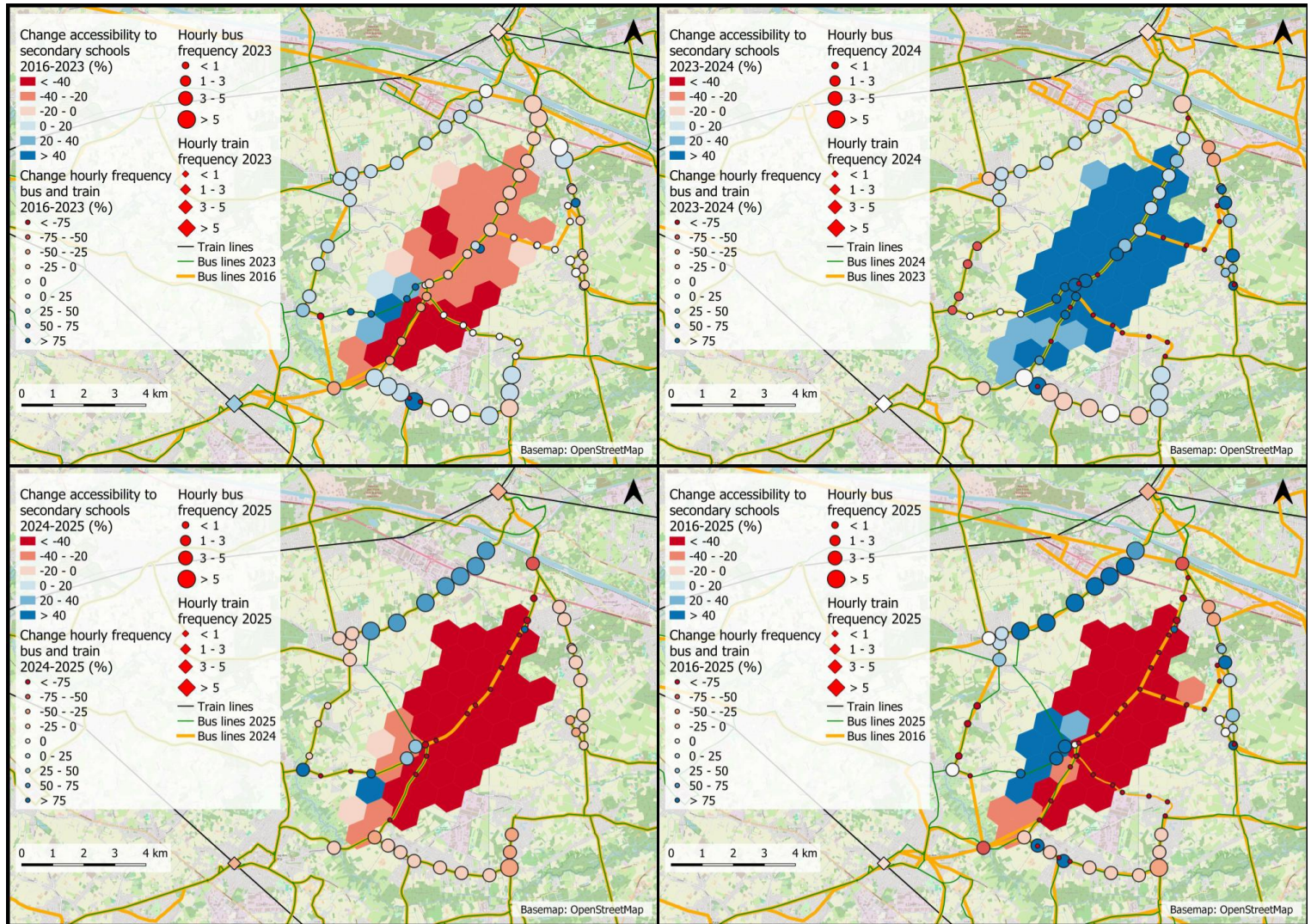


Figure 24: Accessibility to secondary school changes in the Morkhoven case study area. The bus lines of the oldest year considered are depicted in orange, while the bus lines in green represent the updated configuration. The hourly bus (train) frequency of the later year is represented by the size of the dots (prisms), and the percentage change of frequency between the considered dates is portrayed by the colour of the dots. Top left: change between 2016-2023, top right: change between 2023-2024, bottom left: change between 2024-2025 and bottom right: change between 2016-2025.

Between 2016 and 2023, the overall decrease in accessibility is reflected in increased total travel times across nearly all hexagons. Interestingly, for most hexagons, waiting times decreased during this period, which seems contradictory to the reduced bus frequencies observed at most stops. These reduced waiting times might be due to adjustments in the schedules and better coordinated public transit services, or even due to the increased bus times and walking times. The slight increase in walking times can indicate the removal or relocation of intermediate or end stops, as no stops near the case study area were removed. Another potential reason could be that as certain stops are being served less, other stops slightly further away become more interesting, potentially making it worth walking there. Nonetheless, the dominant factor seems to be a significant increase in in-bus travel time,

which aligns nicely with the observed rise in total travel time. Assessing why there is an increase in in-bus times is difficult, but it could be due to route modifications or additional stops.

From 2023 to 2024, total travel times decreased slightly across almost all hexagons, aligning nicely with the computed accessibility change. This can be mainly attributed to increased bus frequencies and the more direct routes implemented during phase 2 of the policy reform. Most walking times remained stable or increased slightly, as was expected given the removal of several bus stops, although there are hexagons with strong increases. While there are indeed longer walking times due to stop removals, Figure 25 does not provide insight into how severely less-mobile people are impacted as a result. Lastly, waiting times and in-bus travel times decreased significantly, probably due to the more streamlined services and fewer stops.

Between 2024-2025, the total travel time jumps strongly upwards, driven by the increased walking time resulting from the suspended central bus line. If users are required to walk longer distances to reach their destination due to the unavailability of buses, bus and waiting times will decrease, replaced with (longer) walking time instead. Nevertheless, a large share of hexagons do not see their bus and waiting times increased; those are most likely the hexagons in the south and along the borders of the case study area. Lastly, while relatively stable between 2016-2024, train travel times decreased for the hexagons in the northern part, while hexagons in the south of the case study saw longer train trips. This does not have a profound impact on accessibility, as the constrained maximum travel time limits train usage.

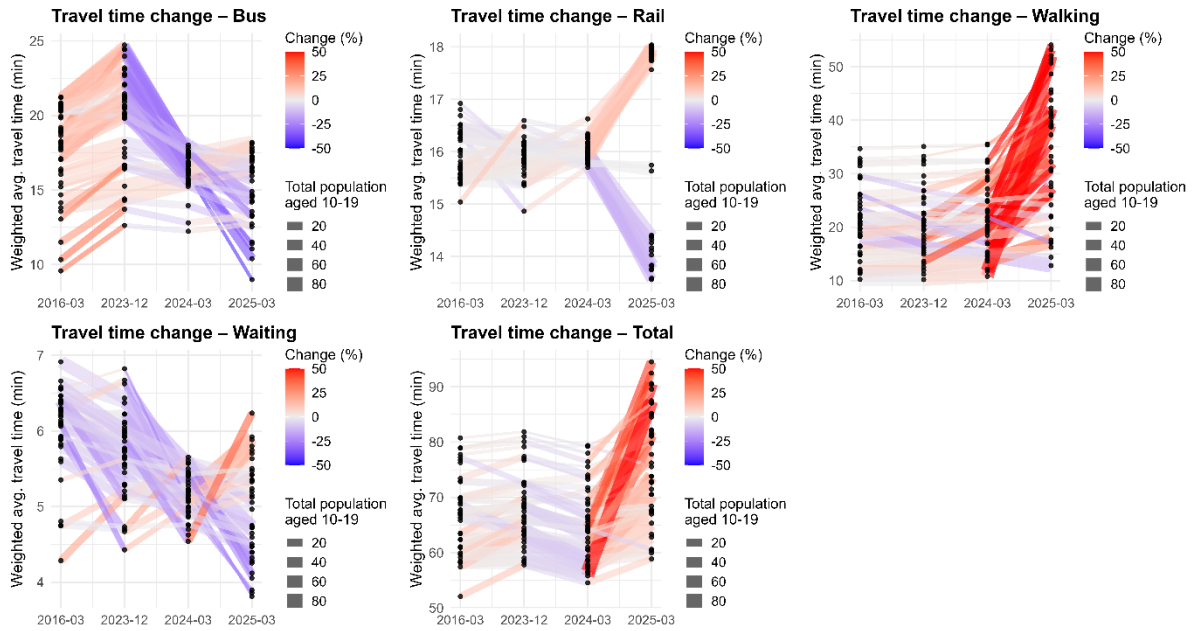


Figure 25: Travel time changes per mode (bus, train, waiting and walking) and the total travel time change between 2016 and 2025. The travel time per mode refers to the average travel time spend on a mode between each hexagon and all considered secondary schools, weighted by the accessibility of the trip. The total travel time is the aggregated version per hexagon across all modes.

To examine at what time of the day network changes are most impactful (Fig. 26), travel times are computed from every hexagon to all secondary schools reached at least once in the Flanders-wide analysis (as in Fig. 25). For each hexagon, trip times are averaged using the trip's accessibility value as a weight, yielding a weighted mean travel time per hexagon (e.g., "Avg. travel time per hexagon in March 2025" in Figure 26). The average case study travel times are then obtained by averaging these hexagon-level values with population weights.

A clear periodic signal is weak in the early morning, partly due to aggregation. Minimum travel times in 2016, 2023, and 2024 occur around 07:30–07:45, roughly 50–30 minutes before typical school starting times. While 2016 and 2023 rise steeply afterwards, the 2024 average remains relatively stable around 45 minutes throughout the morning window, suggesting that the changes of phase 2 created a more evenly distributed service. 2025 shows a similar shape but with an elevated baseline, consistent with the accessibility losses linked to road works, yet from 08:00 onward, it achieves better times than 2016 and 2023.

Around noon, the year-to-year differences are more pronounced. 2016 and 2024 reach their lowest values at 12:00, aligning with typical Wednesday dismissal times. By contrast, 2023 peaks around this moment, a deterioration from 2016. Notably, 2025 consistently remains below 2023 travel times across the noon window despite the road works. The average travel times also reveal a dominant hourly headway in 2023 and 2024 (and less clearly in 2016).

In the evening period, a strongly pronounced periodic pattern is visible in all years. 2025 records the highest average travel times with a baseline near 55 minutes and an evident 20-minute headway. 2016 and 2023 obtain very similar travel times with baselines around 45 minutes between 15:30 and 16:45 and a periodicity comparable to 2025, implying minimal evening effects from network changes between those years. The average travel time in 2024 is consistently lower at a 40-minute baseline and maintains the roughly 20-minute frequency across the entire evening window. Of the three time windows, the evening window is the least affected by changes over 2016–2025.

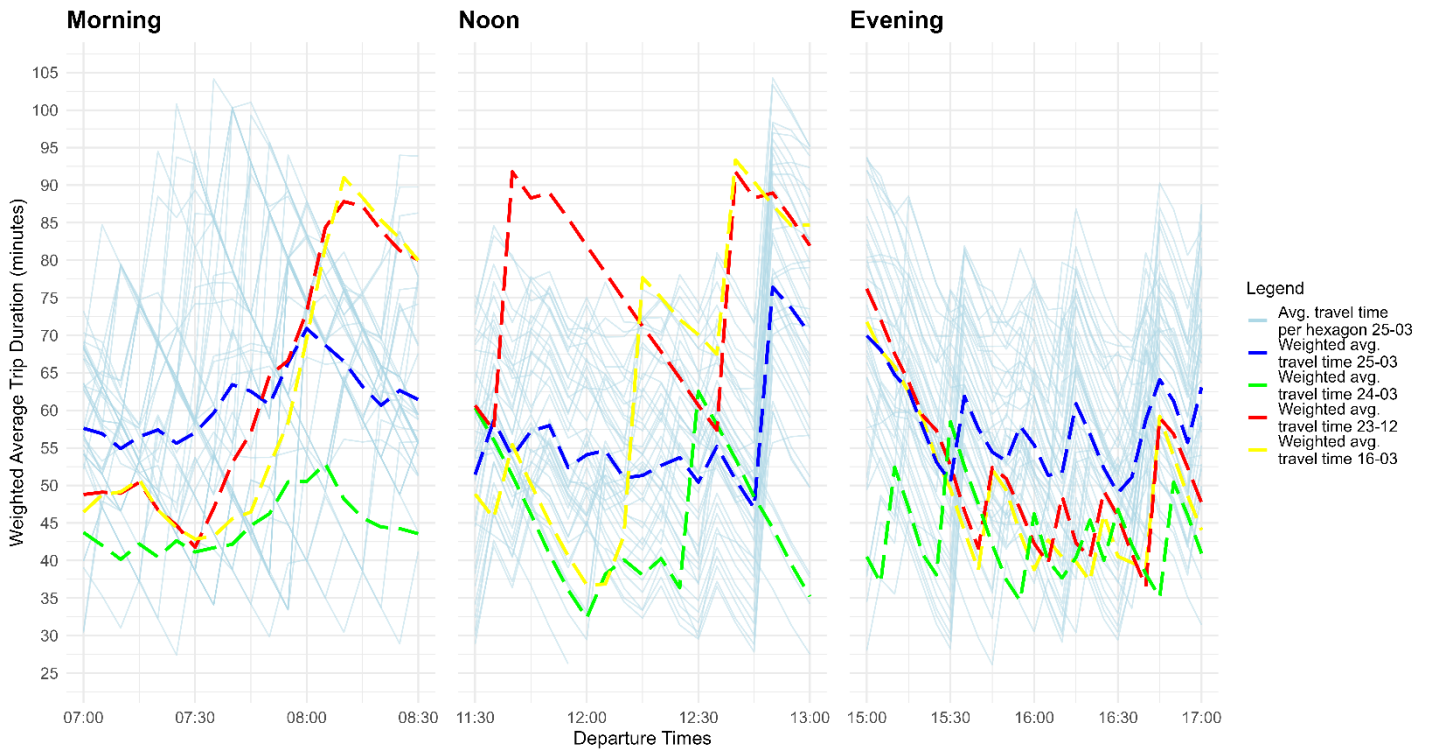


Figure 26: Average travel times at different times of the day for 2016, 2023, 2024 and 2025 across the Morkhoven case study area, weighted by the population in each hexagon. The disaggregated travel times per hexagons in 2025 serve as an illustrative example for the spread of the travel time per hexagon during the day.

#### 4.2.1.2 Accessibility to museums

Compared to local accessibility, the pattern of regional accessibility differs for Morkhoven (Fig. 27). Instead of following the central bus line throughout the case study area, accessibility declines with increasing distance from the high-service routes in the south and east. This pattern is not unexpected given the low operating frequency on the central bus route, which is significantly lower in the weekend and workday timeframes of 08:00-11:00 and 18:00-21:00 compared to workday timeframes of 07:00-09:00, 11:30-13:00 and 15:00-17:00. Other lines show a similar overall reduction in service frequency, resulting from the inclusion of weekend timeframes in the calculations. Nevertheless, the drop from the south to the centre is steep, especially when compared with the drop-off from the north to the centre. While a more detailed look is beyond the scope of this research, an explanation could be a bad connection between bus and rail services, or perhaps due to a flaw in the GTFS data or routing engine.

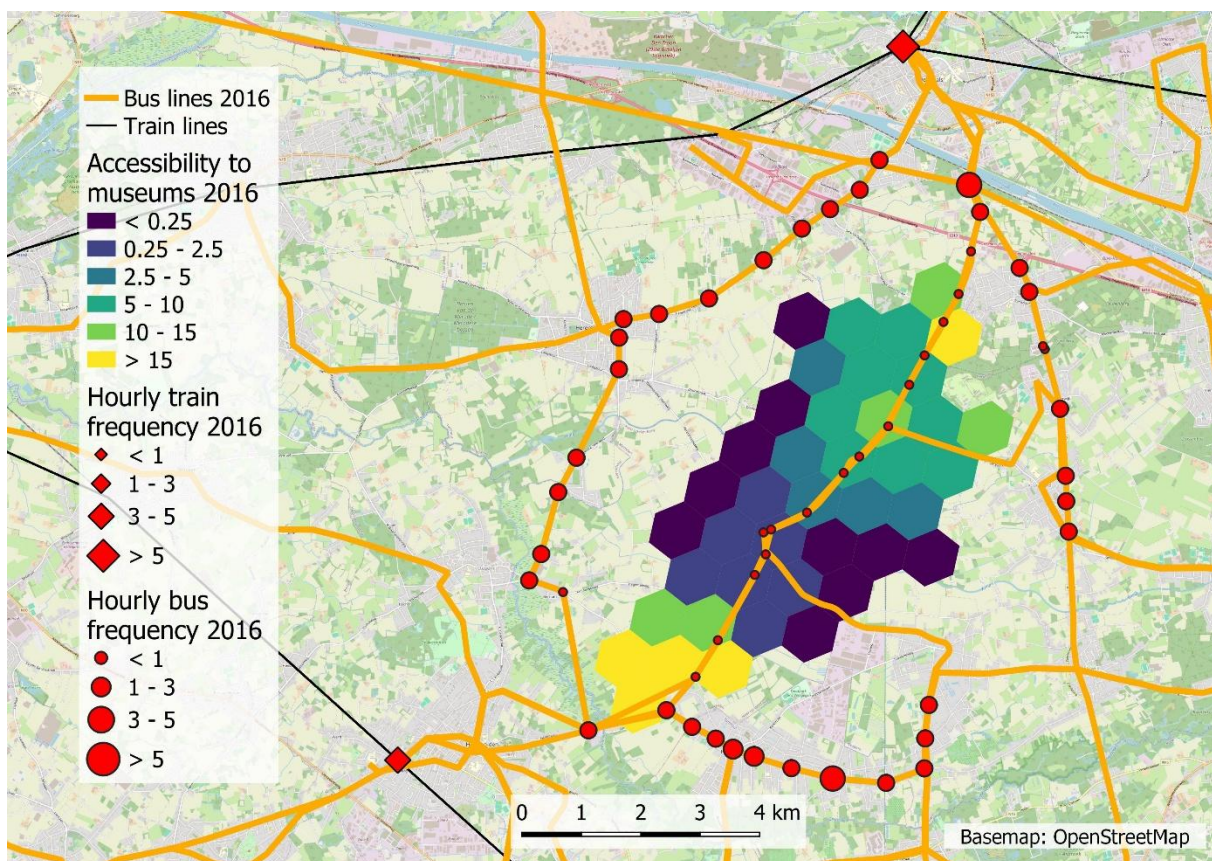


Figure 27: Accessibility to museums in 2016 in the Morkhoven case study area and hourly bus and train frequency at transit service stops near the case study area.

Between 2016 and 2023 the most significant changes were confined to the low-accessibility central part of the case study area (Fig. 28). This coincides with the implementation of an additional bus line in the west, which had a similar, although smaller, effect at local accessibility level. The remaining parts of the study area experienced minor changes as many of the bus frequencies and train frequencies were only slightly modified. This differs from local accessibility level, where a larger decline across the area was observed as the central bus line experienced a large frequency reduction, implying that the timeframes considered in this part of the research were less affected by the transit services changes.

In the second phase of the public transit policy implementation, a strong increase across the entirety of the study area was observed, similar to local-scale changes. Again, reason for the increased accessibility is due to the strong increase in bus along the central public transit axis and increased train frequency in both train stations. The removal of stops seen before is also present for the timeframes considered here. Another similarity is the simplification of the bus network especially in the north of the case study area, which does not have a large impact on accessibility at either scale, due to the distance from the case study area.

Between 2024 and 2025, again a similar pattern is visible. Accessibility declines strongly across the whole study area as a result of lower bus frequencies along all main axes, as well as a reduction in train frequencies in both stations. The reason for this decline remains the same as previously; the removal of a large part of the central bus line due to road works. What is different is that the detour of this part of the line is not accompanied by an increase elsewhere, as was the case at local scale. This due to the strong decline in frequency of the western bus line, which experienced an increase in frequency at local-level. Consequently, the rerouted buses from the centre to the western axis only managed to limit the overall reduction in frequency.

Between 2016 and 2025, a decline in accessibility is observed for the hexagons that obtained high levels of accessibility in 2016. Hexagons in the central part of the case study area received a strong increase in accessibility, mainly due to the small bus line added between 2016 and 2023. Differences between local and regional scale are the stronger declines in bus and train frequencies at regional scale calculations. However, when comparing changes hexagon per hexagon at both scales, the impact of frequency reduction on regional accessibility seems to be more limited, likely due to the usage of longer trip durations.

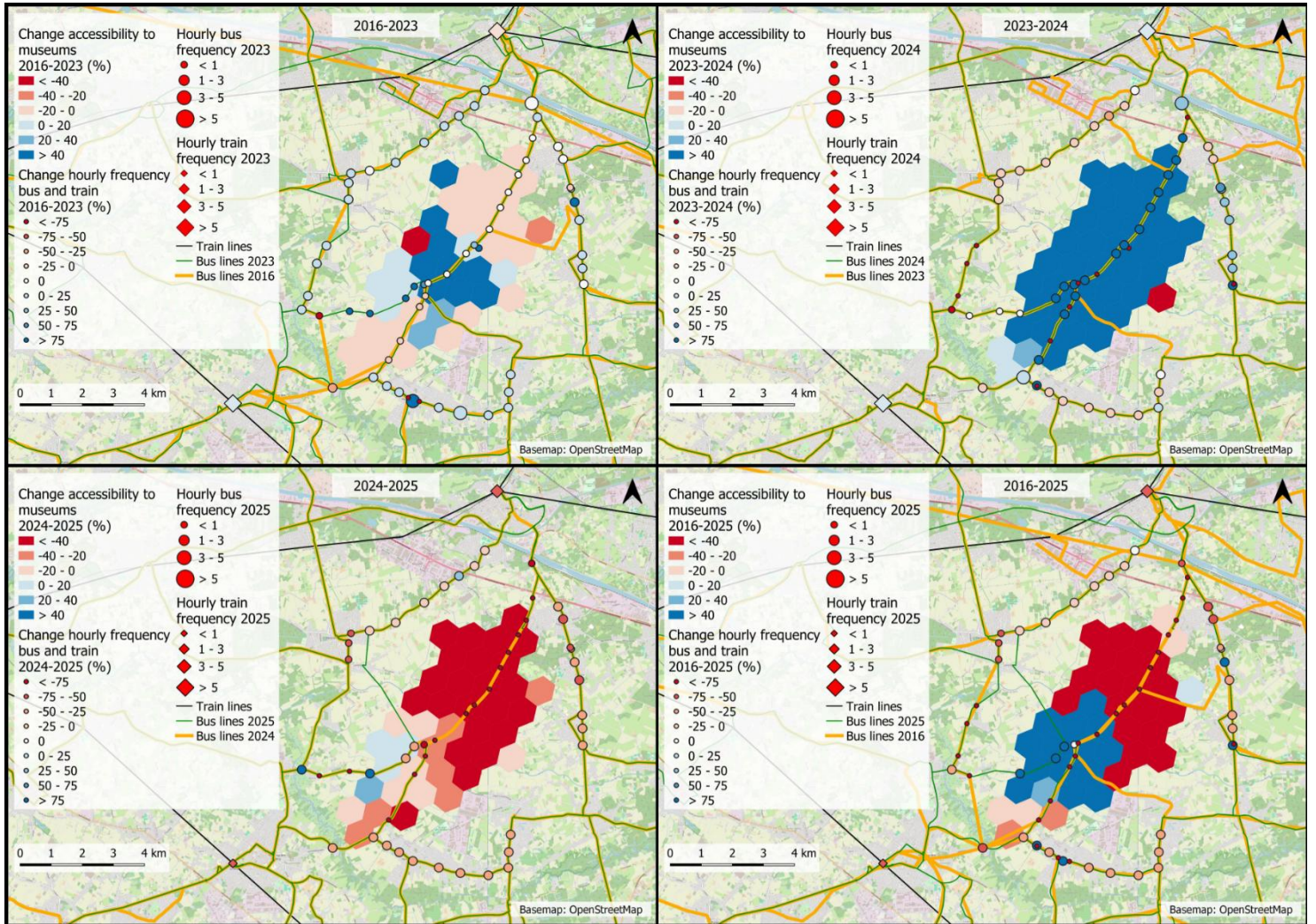


Figure 28: Accessibility to museums changes in the Morkhoven case study area. The bus lines of the oldest year considered are depicted in orange, the while the bus lines in green represent the updated configuration. The hourly bus (train) frequency of the later year is represented by the size of the dots (diamonds), the percentual change of frequency between the considered dates is portrayed by the colour of the dots. Top left: change between 2016-2023, top right: change between 2023-2024, bottom left: change between 2024-2025 and bottom right: change between 2016-2025.

For regional accessibility, the influence of different modes can be estimated as well (Fig. 29). However, there are two differences between this Figure's computation and the computation of Figure 25. Regional accessibility means longer travel times and thus more opportunities reached. This results in large set of Home-Amenity (HA) matrices, with destinations often located quite far away from the home location. Consequently, the detailed breakdown of trips for each HA-pair in different modes is extremely computationally intensive. To reduce the computation times, two adjustments were made: distant locations that were reached less than 50% of the time were discarded, and museums located within a two-kilometre radius from each other were grouped together.

Consequently, the data in Figure 29 can slightly differ from the accessibility patterns seen in Figure 28. One such example is the total travel times between 2016 and 2023. A high proportion of hexagons experiences a decrease or stabilisation in travel time compared to the slight decrease in accessibility seen earlier, although the accessibility decline experienced by most hexagons was smaller than 5%. The stabilisation or decrease in travel times can be attributed to reduced bus travel times, which is the opposite from the observations at local scale, where an increase was visible. Why this is the case is even more difficult to estimate than before, as longer travel times imply more bus routes are available for use. On the other hand, rail travel slightly increased, while walking and waiting times stayed relatively stable apart from some outliers. These latter findings are similar to the patterns seen at the local scale.

Between 2023 and 2024, the total travel times decreased drastically in line with the reduction in accessibility seen at both local and regional scales. While at the local scale, this was mainly due to reduced bus and waiting times, at the regional scale, the causes are mainly reduced walking and rail times. Bus travel times, on the other hand, increased, potentially due to the increased frequency along the central bus line, making it more popular. This could also explain the decrease in walking times, as walking to a high-frequency route in the centre becomes preferable. Lastly, waiting times decreased in this period, potentially due to higher frequency along the central bus line and a better interplay of different public transit services.

Lastly, between 2024 and 2025, accessibility dropped significantly, driven by the bus-line rerouting. Total travel times rise sharply, though they remain below 2016 levels. The muted net increase likely reflects two offsetting dynamics: parts of the study area that had low accessibility in 2016 benefited strongly by 2024, mitigating the reduced accessibility in the northern subarea between 2016 and 2025. Taken together, these trends largely cancel each other out. Expectedly, walking times increased most because of the rerouting of the central bus line. Waiting times remain broadly stable, while in-bus times reached their highest levels, likely because longer trips on alternative lines are required after the central line's removal. Despite a reduction in train frequency, train travel times remain broadly stable, albeit with greater intra-hexagon variability and a few outliers showing strong decreases.

Compared to the change in per-mode travel times at the local scale, patterns for rail, waiting and walking are relatively similar, apart from some oddities discussed above. Interestingly, it is the bus times that are most dissimilar, almost showing the exact opposite pattern. While pinpointing the exact reason is difficult, it could be due to the low frequency of services, resulting in longer travel times or due to bus network alterations.

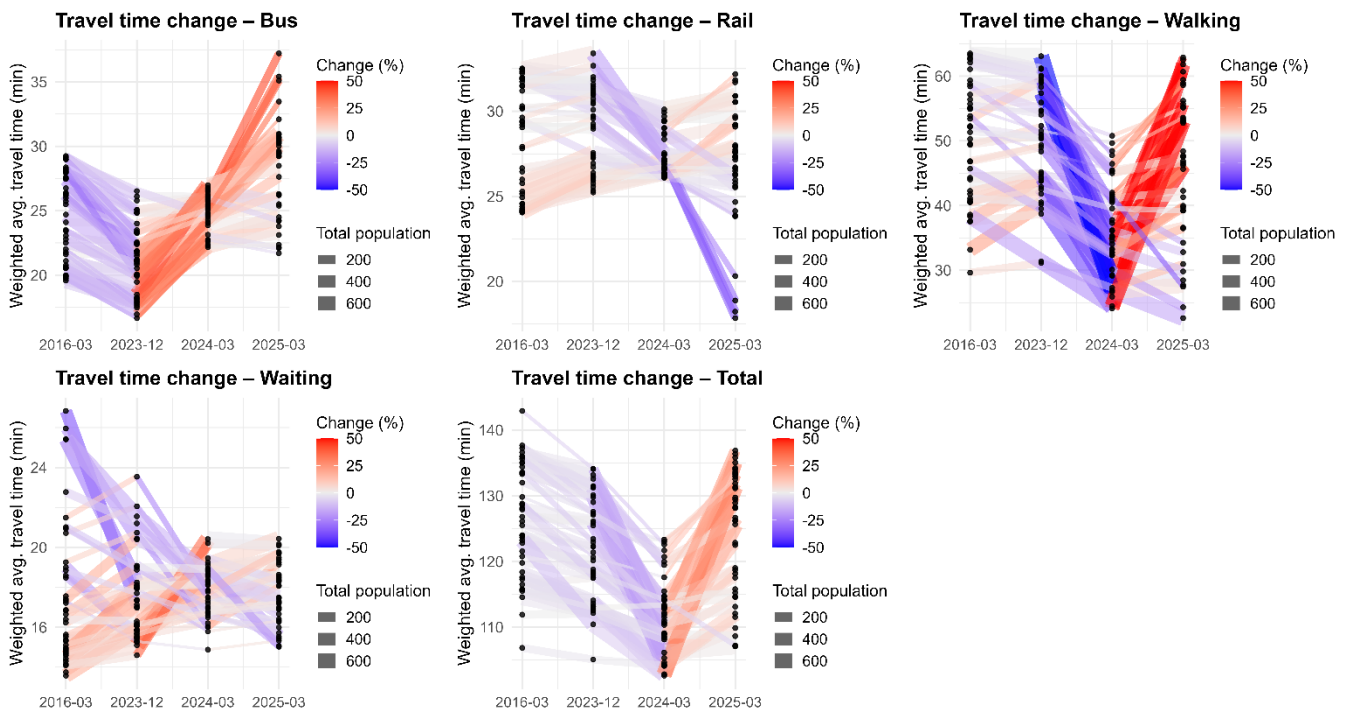


Figure 29: Travel time changes per mode (bus, train, waiting and walking) and the total travel time change between 2016 and 2025. The travel time per mode refers to the average travel time spend on a mode between each hexagon and all considered museums, weighted by the accessibility of the trip. The total travel time is the aggregated version per hexagon across all modes.

Figure 30 concludes the case study with travel times across different times of the day. For regional accessibility, the time windows are 08:00–11:00 and 18:00–21:00 on both weekdays and weekends. On weekday mornings, travel-time differences between 2016, 2023, and 2025 are relatively small, with the average travel times of 2016 and 2023 especially close, consistent with the accessibility maps. 2025 differs slightly, showing a clearer hourly frequency with a baseline around 85 minutes compared to 90 minutes for 2016 and 2023. Inspecting the individual hexagon travel times contributing to the 2025 average reveals pronounced hourly peaks at moments when the area-average is lowest; these correspond to low-population hexagons along the eastern and western edges of the case area. 2024 is the notable outlier, with the lowest baseline of 80 minutes and a less pronounced hourly pattern.

On weekday evenings, the same broad patterns hold: 2016 and 2023 are nearly identical, reaching their lowest values around 18:00, rising to a peak near 19:30, then easing slightly. The 2024 average travel times remain steady at around 75 minutes across the entire window. 2025 is modestly higher again, with a baseline near 85 minutes and a more defined hourly frequency. Across all years, travel times stay relatively stable or decline toward the

end of the window, indicating that late trips remain feasible without substantial additional time.

On weekends, the dynamics are similar. Both morning and evening patterns largely mirror their weekday counterparts. In the morning, 2016, 2023, and 2025 are near-identical, while the 2024 travel time differs as it exhibits clear hourly peaks. In the evening, 2016, 2023 and 2024 are only marginally higher than on weekdays, and 2025 is almost identical to its weekday-evening curve, remaining relatively unchanged throughout the time window. Overall, it is noteworthy that weekend travel times for each year change little despite differences between weekend and weekday public transit service.

Comparing these curves with the secondary-school (local) travel-time, the patterns here yield an interesting contrast; peaks, troughs, and hourly frequency are more pronounced at the local scale. Two mechanisms explain this: First, at the local scale, a single transit line often dominates access to nearby schools, so missing one bus can mean a long wait with few alternatives. At the regional scale, more routing options usually exist to reach a destination. Second, a fixed 15-minute wait has a larger relative impact on a 60-minute local trip than on a 120-minute regional trip, making local accessibility more temporally sensitive.

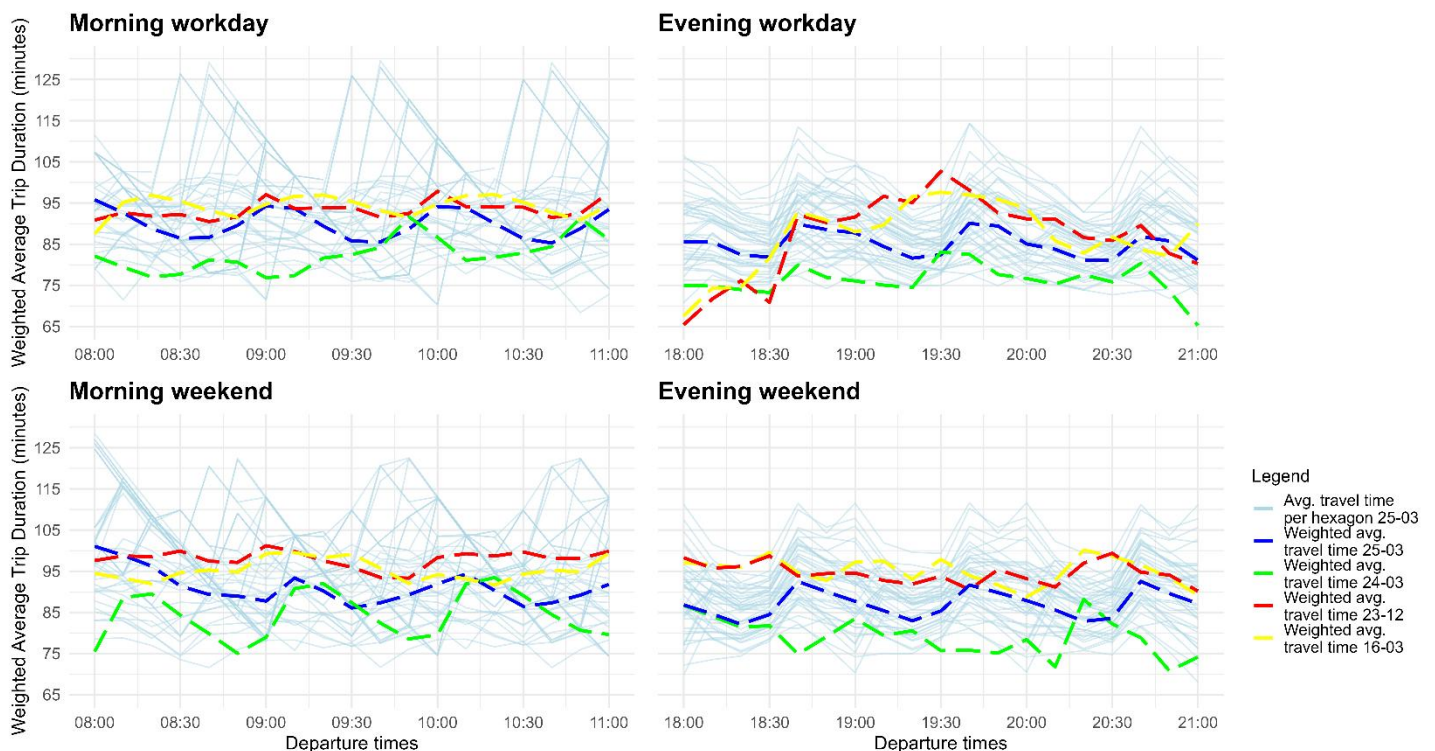


Figure 30: Average travel times to museums at different times of the day for 2016, 2023, 2024 and 2025 across the Morkhoven case study area, weighted by the population in each hexagon. The disaggregated travel times per hexagons in 2025 serve as an illustrative example for the spread of the travel time per hexagon during the day.

#### 4.2.2 Case study 2: Pelt

The second case study focuses on the town of Pelt, its nearby sub-municipalities and the larger region of northern Limburg. It has an area similar to the previous case study at around 33 km<sup>2</sup>, but a population of around 19,000 inhabitants, of which 2,000 are aged 10 to 19. Pelt is located close to the Dutch border and roughly between Mol and Maaseik. Compared to Morkhoven, Pelt is a less rural area with a denser bus network, two train stations and secondary schools within the confines of the case study area. The bus and train network offer connections to other larger cities and municipalities in the region (Figure 31).

11 lines served the region in 2016, with most of them oriented in a north-south direction between Pelt and the cities of Hasselt and Genk. Other smaller lines connected Pelt and its nearby eastern and western surroundings. Lastly, there is a bus connection between Pelt and the cities of Leuven and Brussels, mainly meant for students attending university there. By 2023, the number of bus lines had almost tripled to 30 lines, with both the number of short lines and long-distance lines increasing, resulting in a denser spatial bus coverage. The most notable changes are the removal of the line to Leuven and Brussels and the addition of lines to Mol and Maaseik. In 2024, the number of lines halved to 15, with most of the spatial coverage retained, although the regions east and south of the case study area lost most, but still had minor coverage. In 2025, the trend of limited change persisted, with no lines added or removed. The most notable alteration was the shortening of the route in the north of the case study area.

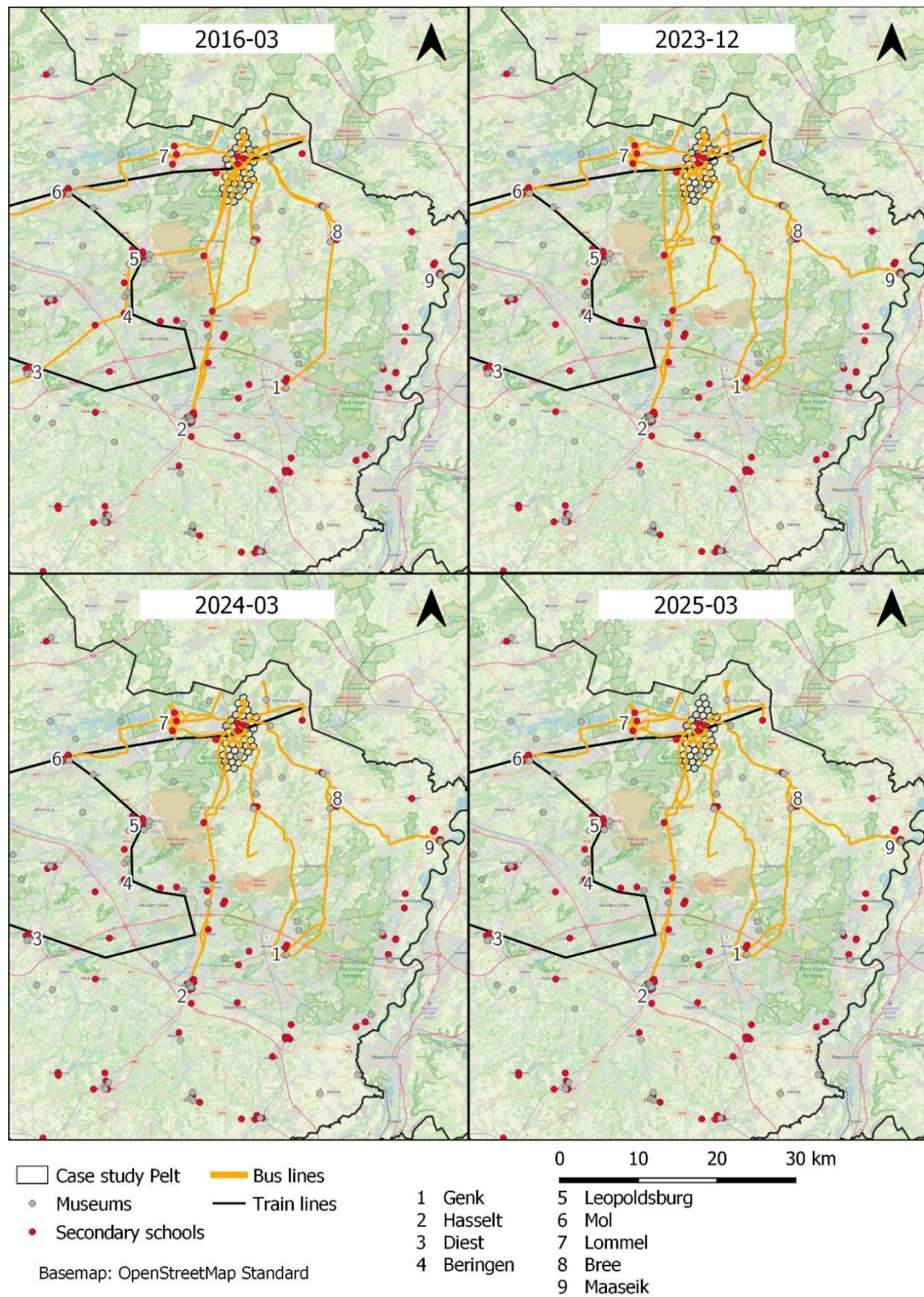


Figure 31: Overview of the bus lines and train lines that pass in the vicinity of the Pelt case study area for 2016, 2023, 2024 and 2025. Overview of the museums and secondary schools in the larger vicinity around Pelt.

#### 4.2.2.1 Accessibility to secondary schools

Secondary school accessibility in Pelt in March 2016 is shown in Figure 32. The highest levels of accessibility can be found in the centre of the municipality, as the secondary schools are located there, as well as the major bus and rail lines. Accessibility declines slightly when moving from the centre to the eastern and western sides of the case study area, which are still supported by high-frequency bus lines. The drop-off is steeper when moving from the centre to the northern and southern parts of the case study, as bus lines are less dense and frequencies decrease. Similar to the Morkhoven case study, accessibility follows the major bus lines quite nicely, which is clearly visible for the southern axes. Apart from the major bus lines, there are three low-frequency lines: in the north, southeast and west. As seen in the previous case, they offer relatively limited accessibility to the broader case study area, but changes in their frequency might strongly alter accessibility of nearby hexagons.

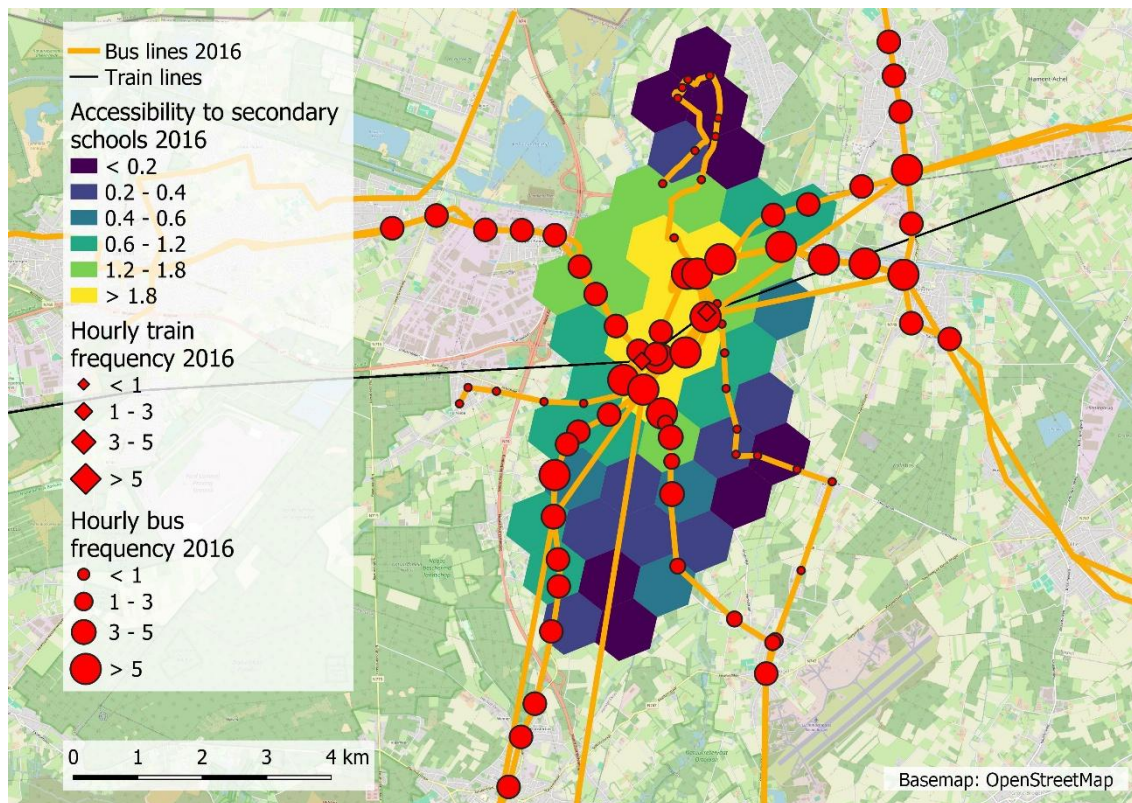


Figure 32: Accessibility to secondary schools in 2016 in the Pelt case study area and hourly bus frequency at bus stops within a range of 1500m of the case study area (red dots). The bus lines are depicted in orange.

Between 2016 and 2023, most of the case study area experienced declines in accessibility, with only the northern, eastern, and western edges showing slight increases (Fig. 33). These patterns align closely with changes in bus frequencies and stop locations. While frequencies on the main lines generally fell, they remained stable on the smaller lines, which helped keep accessibility steady in the low-accessibility zones along the edges. In the north, the increase likely stems from an additional eastbound route and higher-frequency stops just to the south. Along the western edge, gains coincide with added nearby stops, whose positive effects appear to outweigh both the frequency reductions and the removed stops.

The general decline deepened in 2023-2024. Although major lines in the south and east saw frequency increases, these were insufficient to counteract the area-wide losses. Only in the southern sector were gains obtained. The dominant driver of accessibility change was the continued reduction in frequency on the high-frequency east-west corridor. Two further factors also contributed: 13 stops, mainly on high-frequency lines, were no longer served, and minor lines that had remained stable through until 2023 saw frequency cuts, producing strong accessibility declines in the east and northeast.

Between 2024 and 2025, this downward trend eased slightly, except in the northern hexagons, where the minor bus line was abolished entirely, causing a marked drop in accessibility. As hypothesised before, even if minor lines do not deliver high accessibility, they strongly shape accessibility for the hexagons they traverse. Most other lines remained stable or saw modest frequency increases, lifting accessibility across much of the area. Notable exceptions include declines on the line from Pelt centre to the east and a minor line heading south. Train frequencies fell at both stations, but their effects appeared limited.

Overall changes from 2016 to 2025 evidenced a subtle northward gradient in accessibility decline. The far south improved slightly due to higher frequencies on nearby lines. The centre saw broad declines as several lines had their frequency reduced, partly cushioned by increased service on the main southern line. Finally, the northeastern and southeastern areas registered losses mainly linked to the removal of stops or substantial reduction of minor bus lines crossing these zones.

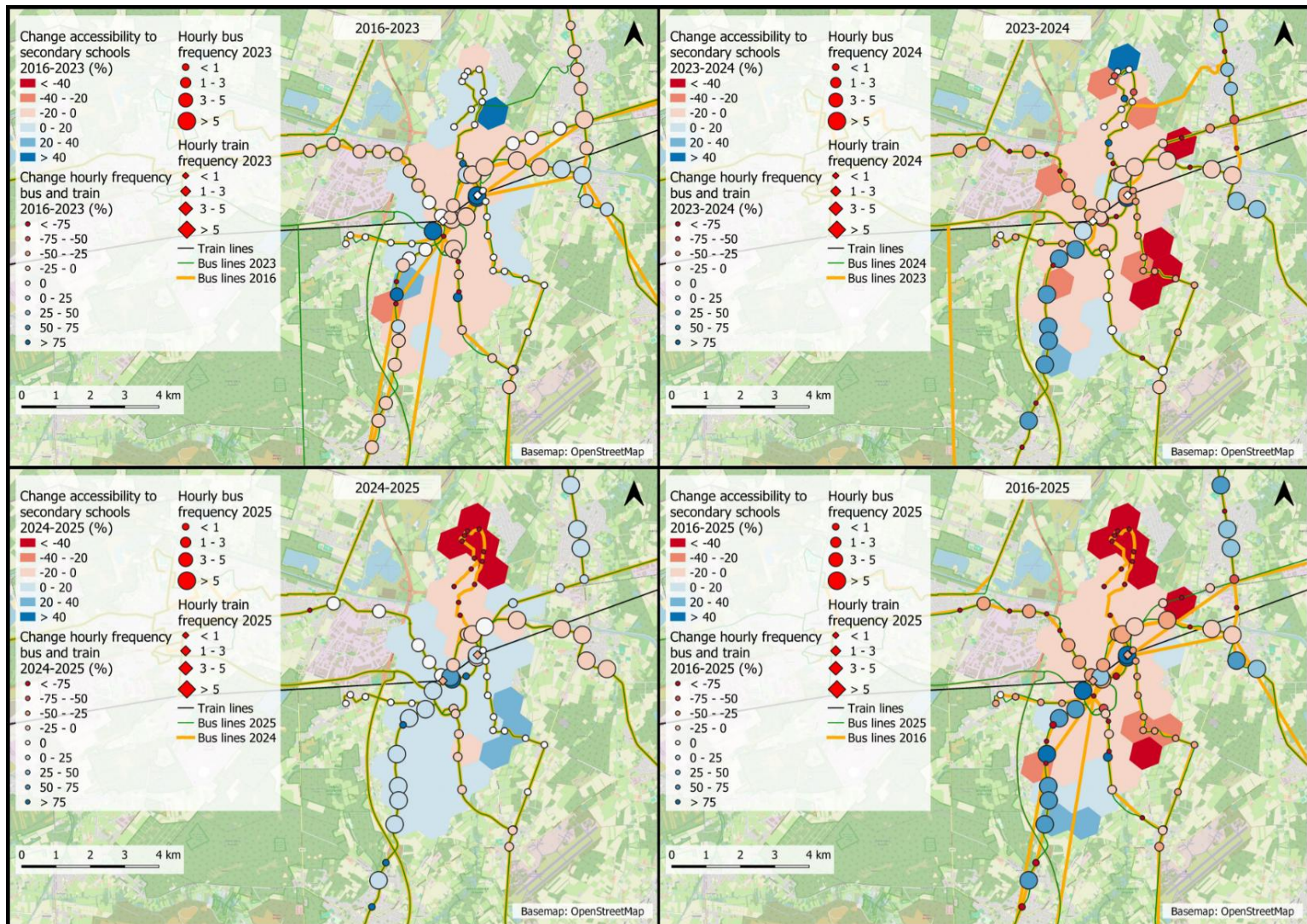


Figure 33: Accessibility to secondary school changes in the Pelt case study area. The bus lines of the oldest year considered are depicted in orange, the while the bus lines in green represent the updated configuration. The hourly bus (train) frequency of the later year is represented by the size of the dots (diamonds), the percentual change of frequency between the considered dates is portrayed by the colour of the dots. Top left: change between 2016-2023, top right: change between 2023-2024, bottom left: change between 2024-2025 and bottom right: change between 2016-2025.

When looking at the different modes that contribute to the total travel time, some interesting observations can be made (Fig. 34). The pattern of total travel-time change between 2016 and 2023 mirrors the accessibility results: most hexagons show only modest increases or decreases, while four hexagons exhibit sharp reductions. These four also gained accessibility, but may partly reflect the different calculation setup used explained earlier. By component, walking times remained broadly stable, with a few increases where nearby stops were removed. Waiting times rose slightly on average, with substantial variation across hexagons, potentially due to frequency changes and stop removals. Bus and rail times changed little overall; bus times edge down slightly while rail times edge up minimally.

Between 2023 and 2024, the total travel times increased across most hexagons, including the four that had improved previously. This aligns with earlier results and stems from higher walking, bus and waiting times. Three mechanisms are likely to drive this increase: first, a simplified network with fewer lines can lengthen bus travel as direct routes are no longer available. Secondly, the removal of many stops lengthens walking times and lastly, reduced bus frequencies raise waiting times. In contrast, rail travel times declined for most hexagons, suggesting faster connections to nearby municipalities.

The last time frame considers the travel time between 2024 and 2025, where the total travel times remained largely stable, though a couple of hexagons showed strong swings. Walking times remained similar to 2024 except in the far north, where the removal of a local bus line forced longer walks to reach secondary schools or transit stops. With the frequency increases on the southern line, waiting times were generally stable or slightly lower. Increases are concentrated near lines with reduced frequency or close to the stations. Bus travel times remained fairly steady, though inter-hexagon variability grew. As is the case elsewhere, pinpointing causes is difficult given the limited network changes and information. Rail times ticked up again for most hexagons, ending slightly above 2024 levels. Here, too, limited auxiliary data prevents a firmer attribution.

Excluding the 2025 travel times, the relative modal shares of the total travel time resemble those observed for secondary schools in the Morkhoven case. This is interesting as Pelt has a more robust public-transport network, yielding average total travel times 10–20% lower than in Morkhoven. The similarity in modal shares is likely a coincidence rather than actual similar network performance.

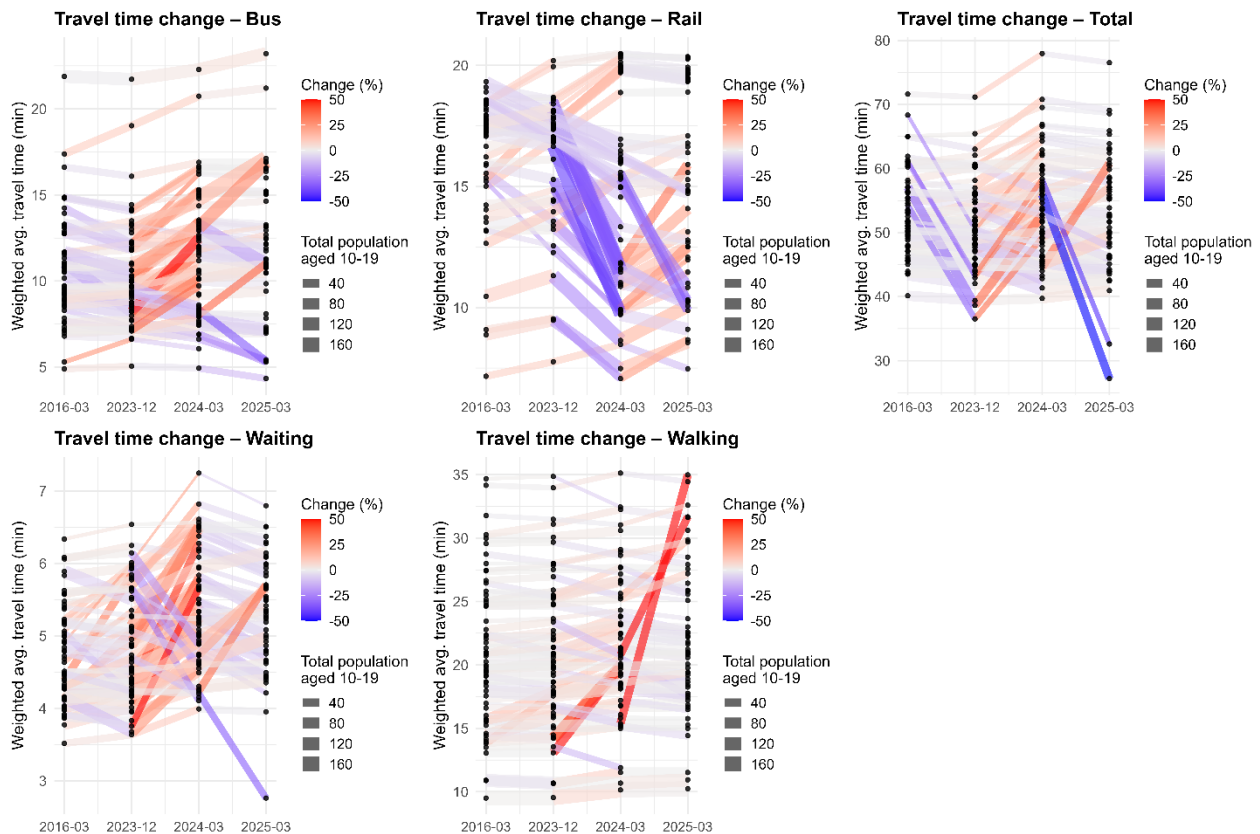


Figure 34: Travel time changes per mode (bus, train, waiting and walking) and the total travel time change between 2016 and 2025. The travel time per mode refers to the average travel time spend on a mode between each hexagon and all considered secondary schools, weighted by the accessibility of the trip. The total travel time is the aggregated version per hexagon across all modes.

Figure 35 breaks down local accessibility in Pelt by time of day. In the morning window, population-weighted mean travel times are similar across 2016, 2023, 2024, and 2025, with a steady baseline around 30 minutes. The main deviation is a bump in 2025 between 07:30 and 08:00, the period when most students depart for school. Although the absolute increase is small, it represents roughly a 10–20% increase relative to other years. Because it coincides with peak departure times, it might create a perception of worsening service, even though the average across the full morning window is comparable to previous years.

This pattern of limited year-to-year variation persists at noon and in the evening. The population weighting attributes the greatest influence to high-population hexagons in central Pelt, where accessibility and total travel times changed little. Accordingly, the weighted averages vary only slightly. The per-hexagon curves, however, show wide dispersion: central, high-population hexagons record the shortest times, while peripheral, low-population hexagons, especially along the northern and southern edges, have the longest travel times and the largest percentage swings in accessibility. This contrasts with the previous case study, which had a smaller, more dispersed population, reflected in the shape of the more varied average travel time curves.

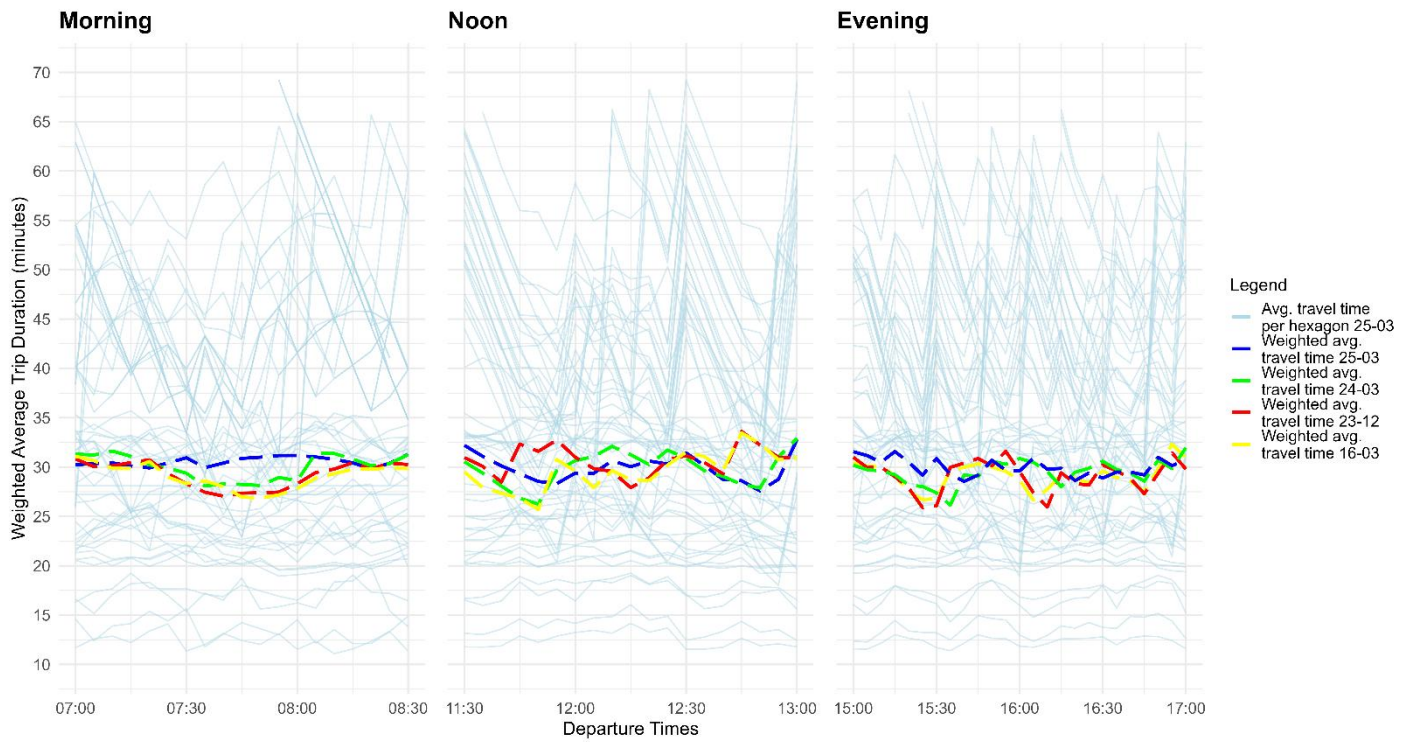


Figure 35: Average travel times to secondary schools at different times of the day for 2016, 2023, 2024 and 2025 across the Pelt case study area, weighted by the population in each hexagon. The disaggregated travel times per hexagons in 2025 serve as an illustrative example for the spread of the travel time per hexagon during the day.

#### 4.2.2.2 Accessibility to museums

The final part of the case study analysis consists of accessibility to museums in Pelt (Fig. 36). Accessibility values show a similar, although more concentric pattern around the centre of Pelt, with its train stations and high density of bus stops. Accessibility strongly declines from the centre to the north and south along the more sporadically served bus lines. The available bus services also differ from the time frames used for local accessibility calculations. Frequencies are lower along both high and low frequency bus lines; only train frequency remains similar. Apart from that, the minor bus line running from the centre to the west is not served during this time frame, and a part of the easternmost line going north-south saw some stops close to the centre not being used. The reduced frequency on nearly all transit routes was also seen in the Morkhoven case study and is the result of the inclusion of weekend time frames, as public transit services operate in reduced form compared to their weekday services.

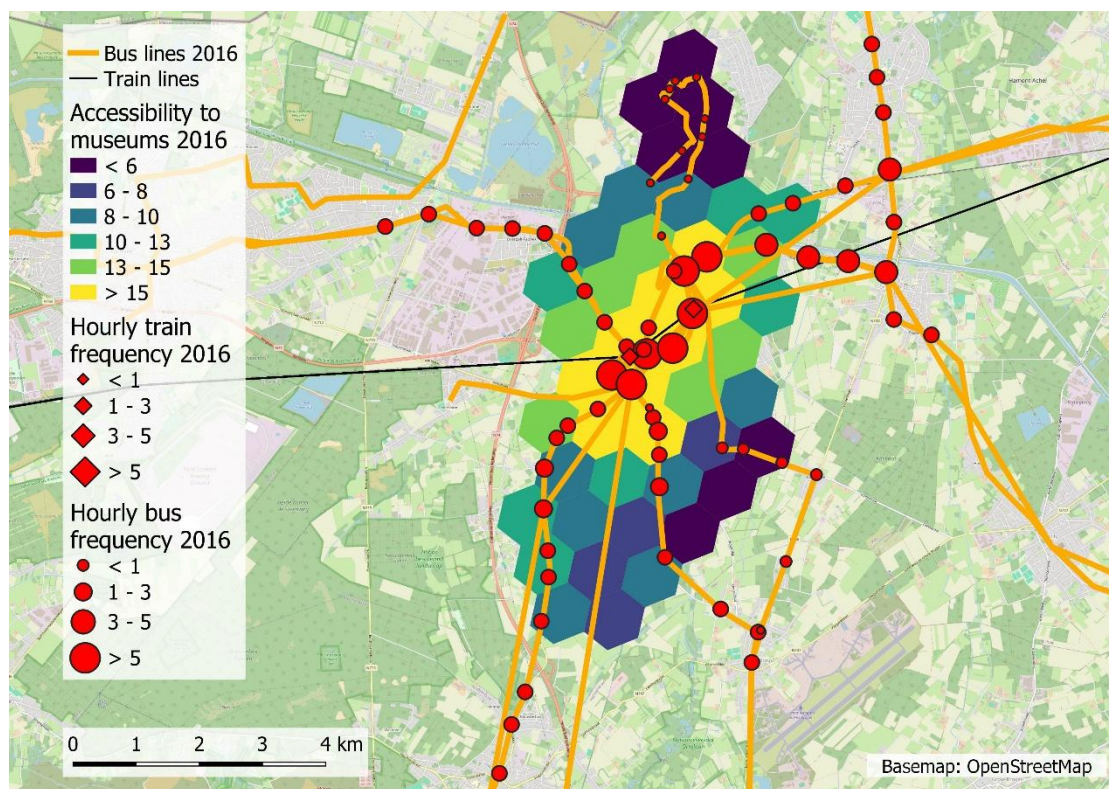


Figure 36: Accessibility to museums in 2016 in the Pelt case study area and hourly bus and train frequency at transit service stops in and near the case study area.

When comparing the level of accessibility between 2016 and 2023, only limited change occurred (Fig. 37). The south and parts of the centre improved slightly, consistent with higher frequencies on the southern bus line. The line from the centre to the east also gains frequency, but this does not translate into accessibility improvements. Lines in the east and north remain largely stable, though the inbound line at the northwestern boundary is operated in reduced form, which is reflected in lower accessibility there. In the south, several stops are withdrawn, reducing accessibility, especially in the southeast, where the through-running line is no longer served during the analysed windows (08:00–11:00 and 18:00–21:00, weekdays and weekends). Although the average magnitude of change is similar to the 2016–2023 local accessibility results, some hexagons are affected differently; for example, the eastern edge shows no regional-scale improvement despite local-scale gains.

Between 2023 and 2024, declines in the centre persist as frequencies on the east–west lines continue to fall and more stops are decommissioned. The north shows a mixed picture, with both decreases and increases. By contrast, the south experienced gains across all hexagons. While higher frequency on the main north–south line plays a role, other factors might also be at play. Interestingly, the findings run counter to the local-scale analysis, where the south lost accessibility despite increases on the same north–south line, possibly because the minor line in the southeast operated at reduced frequency at the local scale.

The following period, between 2024 and 2025, saw declines spread across the area as service was reduced at both train stations and at most bus stops. As the northern bus line is discontinued altogether, losses deepened there. Although this change is also visible at the local scale, the local analysis did not show declines in the south and centre because of increased frequency on the main southern line during the local time windows.

When combining these findings for 2016–2025, a familiar north–south gradient emerges, with declines in the north and improvements in the far south, as observed during the local analysis. However, regional-scale declines are more severe: more stops were decommissioned and frequencies were reduced across multiple lines, with the southern line the main exception. The combination of service cuts and a lower baseline frequency amplified accessibility losses relative to the local scale. Only the far-southern hexagons obtained net gains, but even there, the improvements are unlikely to be solely attributable to the frequency increase on nearby lines.

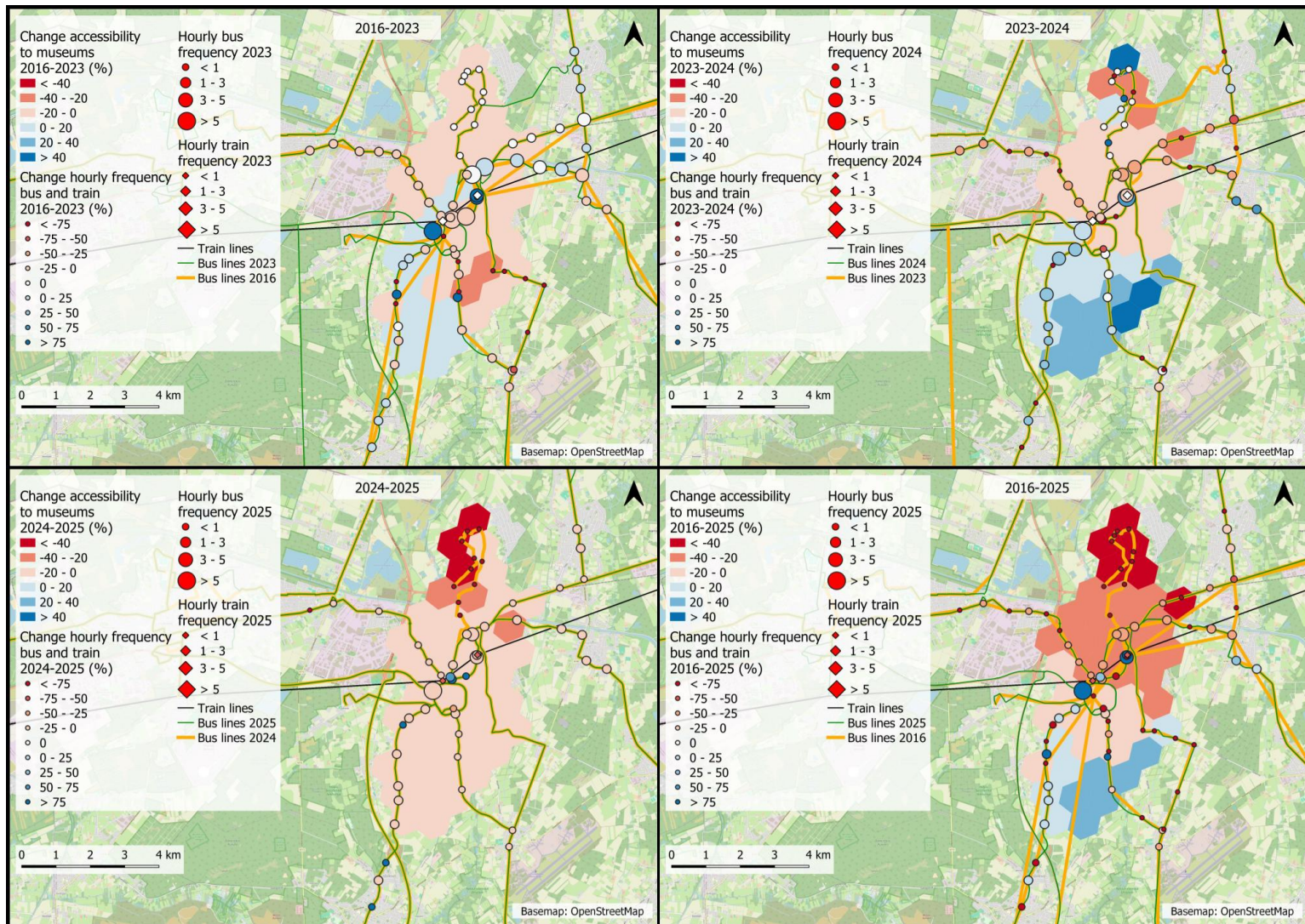


Figure 37: Accessibility to museums changes in the Pelt case study area. The bus lines of the oldest year considered are depicted in orange, the while the bus lines in green represent the updated configuration. The hourly bus (train) frequency of the later year is represented by the size of the dots (diamonds), the percentual change of frequency between the considered dates is portrayed by the colour of the dots. Top left: change between 2016-2023, top right: change between 2023-2024, bottom left: change between 2024-2025 and bottom right: change between 2016-2025.

To check whether factors beyond service frequency shaped the regional accessibility results, per-mode travel times are examined (Fig. 38). In 2016–2023, the total travel time increased slightly for most hexagons, with a smaller set showing declines, consistent with the accessibility changes. Walking is broadly stable, with some increases where nearby stops were removed. Waiting times rose modestly on average but varied widely across hexagons, reflecting frequency cuts and stop closures. Bus and rail travel times changed little overall, with bus times remaining stable and rail times edging up.

The same dynamic persists in 2023-2024. High-population hexagons generally saw higher total travel times, while lower-density hexagons often stabilised or improved. Changes are driven mainly by increased bus and rail times, although some hexagons benefit from

markedly better bus/rail connections. Waiting times largely stabilised despite continued frequency reductions on the east–west corridor. Walking times remained similar to 2023 for most hexagons, with many posting shorter walk times, seemingly at odds with stop removals, but plausible if changes at intermediate or terminal stops shortened parts of the walk legs.

In the 2024–2025 period, a paradox seemed to emerge: although accessibility declined across the case area, the aggregated total travel time from the per-mode decomposition fell. As noted earlier, the computation used for these per-mode curves differs from the overall accessibility metric, which likely contributed to this discrepancy. By component, walking and in-vehicle bus time are similar to 2024 or slightly higher, whereas waiting and rail times drop notably. The waiting-time decrease is hard to reconcile with widespread frequency cuts at both bus and rail stops. One possibility is that timetable adjustments at intermediate or terminal stops shortened transfer waits. However, such changes would need to be widespread along multiple relevant routes to explain the area-wide pattern, but the detailed train- and bus-network data needed to verify this is lacking.

Several factors may jointly explain why the per-mode total travel times fall even though the accessibility decreased. These factors include methodological differences between the per-mode travel time computation and the overall accessibility calculation, as occasional misalignment and oddities have already been noted previously. The filtering of non-frequent trips in the per-mode analysis, which omits multiple possible trips, could also be a reason. Additionally, the amenity grouping to improve efficiency, which combines nearby amenities in a single point, could potentially alter computed travel times. The discrepancy likely reflects a combination of these factors, though notably, a dissimilarity of the same magnitude does not appear in other years or in the Morkhoven results.

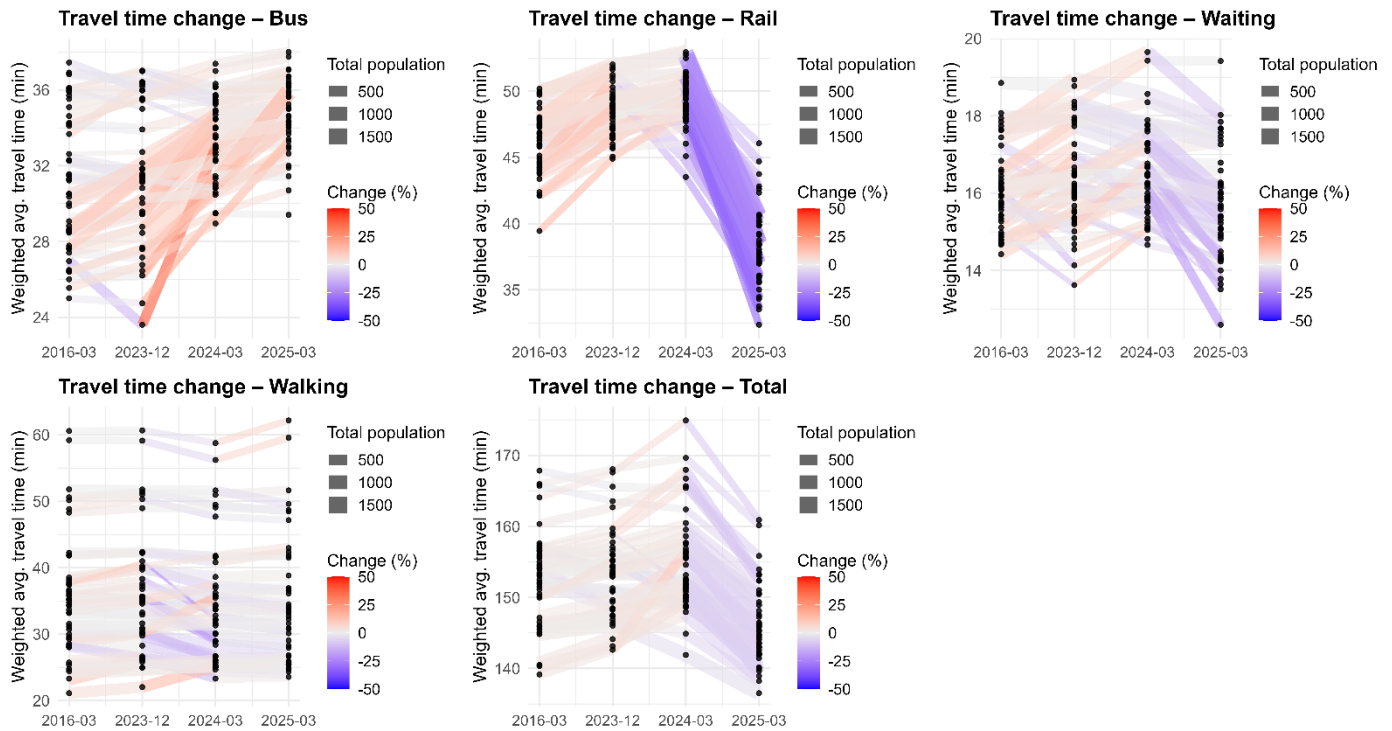


Figure 38: Travel time changes per mode (bus, train, waiting and walking) and the total travel time change between 2016 and 2025. The travel time per mode refers to the average travel time spend on a mode between each hexagon and all considered museums, weighted by the accessibility of the trip. The total travel time is the aggregated version per hexagon across all modes.

Figure 39 can be used to pinpoint when the unexpected travel-time reductions occur, as the same dataset is used as for Figure 38. On weekday mornings, the 2016, 2023, and 2024 curves are nearly identical in both level and shape, while 2025 diverges: from 09:00–11:00, its average total travel time is about 10% lower than the other years. On weekday evenings, 2016 and 2023 again track each other closely with a clear hourly periodicity. In 2024, average times increase, and the evening curve loses its periodicity after about 18:45, obtaining higher values. 2025 records the lowest evening times overall, with a baseline near 75 minutes, matched only by the troughs of the 2016/2023 cycles.

On weekends, morning and evening patterns are similar: 2016 and 2023 remain nearly identical and lack a pronounced hourly periodicity. 2024 shows a slight improvement in the morning average travel time relative to earlier dates and is marginally better than 2025 in the evening. Even so, 2025 delivers lower average times in both morning and evening windows, especially on weekdays. The findings of Figure 39 rule out the idea that the anomaly is confined to a particular time of day, although morning times between 09:00 and 11:00 are particularly low. Still, the cause for the discrepancy remains unclear.

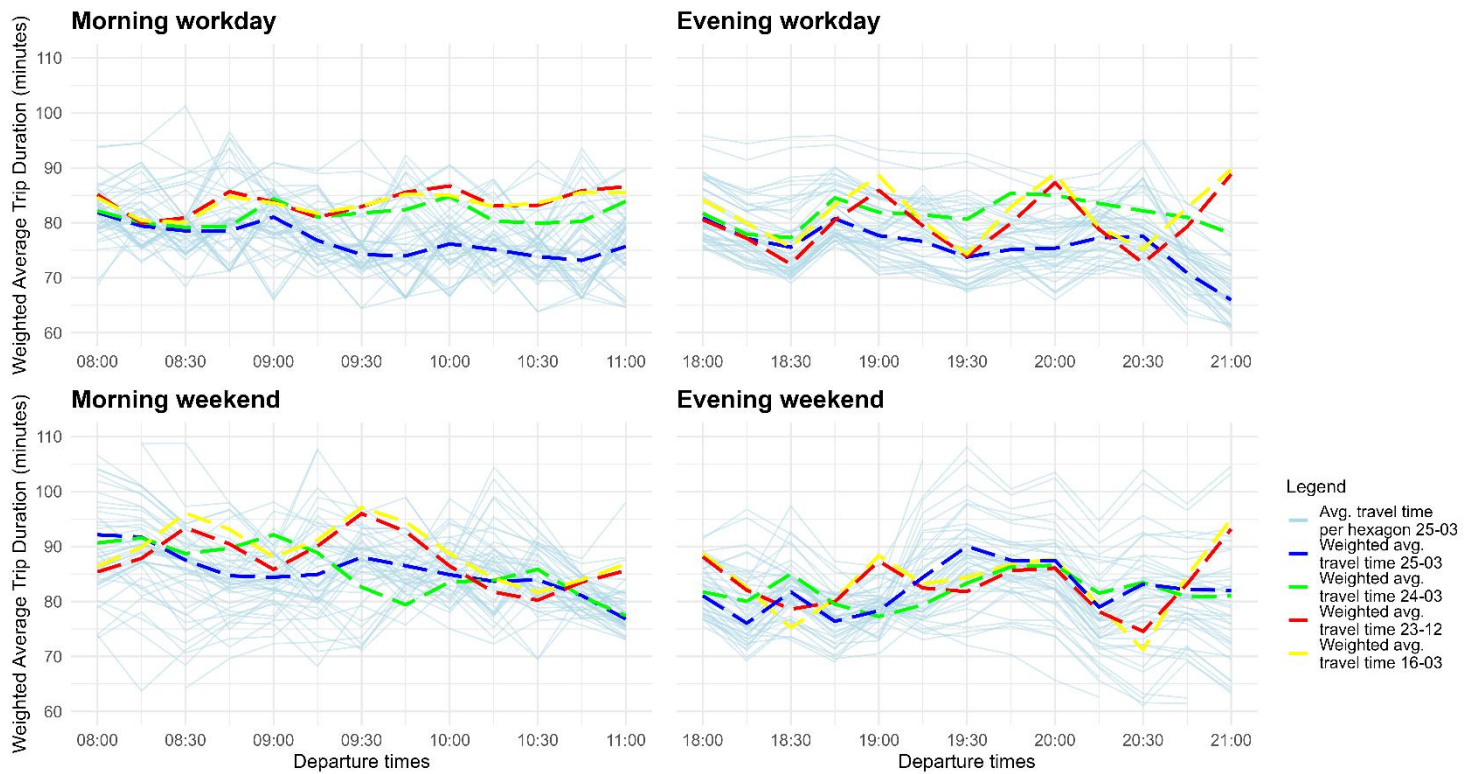


Figure 39: Average travel times to museums at different times of the day for 2016, 2023, 2024 and 2025 across the Pelt case study area, weighted by the population in each hexagon. The disaggregated travel times per hexagon in 2025 serve as an illustrative example for the spread of the travel time per hexagon during the day.

### 4.3 The current stop: Where did the results bring us?

All described and discussed results bring us to the question: What is the current stop of our trip, where did the results bring us; how do the findings relate to this study's research questions? The first research question investigates *how and to what extent local accessibility to secondary schools and regional accessibility to museums evolved across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025, and how these trajectories differed between high-density and low-density areas.*

#### 4.3.1 Long-term accessibility change in Flanders and the BCR

Ideally, accessibility would be assessed immediately before and after each policy phase. However, the GTFS data needed to isolate the effects of phases 0 and 1 (implemented on 1 January and 1 July 2023) were not available without accepting a long buffer in which unrelated network changes could occur. Consequently, the analysis of policy-driven change focuses on phase 2 (2023–2024, effective 1 January 2024) and phase 3 (2024–2025, effective 1 January 2025).

Despite the media and political backlash to phase 2 often emphasised the removal of 3200 bus stops (VRT NWS, 2024a; 2024b; 2024c), average accessibility to both secondary schools (local scale) and museums (regional scale) remained stable or improved slightly between 2023 and 2024. Local accessibility changes ranged from  $-1\%$  to  $+3\%$ , while regional accessibility rose between 0 and 8%. These gains occurred consistently across all population-density brackets, though variation between hexagons remains substantial, especially in low-density areas at the local scale. Note that results reflect scheduled service only; operational issues (delays, strikes, overcrowding) that often drive public dissatisfaction (VRT NWS, 2024d) are not captured. But from a theoretical, schedule-based perspective, phase 2 did not degrade accessibility; it slightly increased it. That said, the large-scale removal of stops does warrant further study for mobility-impaired users.

The 2024–2025 period, aligning with phase 3, paints a different picture: both local and regional accessibility declined sharply, with roughly 75% of the population experiencing lower service levels. Paradoxically, this received less media attention, perhaps because it lacked the perception of a large change like a mass stop removals. Compared by population density, the regional scale is hit hardest: most brackets show a roughly 10% drop, versus an average decline of 3% at the local scale. These losses account for a large share of the total accessibility change over 2016–2025 and completely overturned the gains made during phase 2.

Over the full period 2016–2025, local and regional accessibility trajectories diverge significantly. Regional accessibility rose during 2016–2023 (+3–9%), while local accessibility fell (–1–5%). While phases 0 and 1 fall within these windows, their distinct effects cannot be isolated, leaving their influence on the 2016–2023 accessibility unknown. Between 2023–2024, accessibility to secondary schools increased, albeit to a lesser extent than the increase for museums. Between 2024–2025, museum accessibility dropped strongly, while secondary-school accessibility decreased more modestly. This provokes some thoughts on why the magnitude and dynamics of local and regional accessibility differ. Three factors offer a likely explanation for this discrepancy. First, different opportunity sets (museums vs schools) imply different trip patterns and thus different sensitivities to network changes. Secondly, different time windows were used for computation, complicating direct comparison. Lastly, longer maximum travel times at the regional scale expose more trip segments to change.

In sum, local accessibility showed a long-term decline between 2016 and 2025. This started with a 2016–2023 decrease, halted by the implementation of phase 2, but the declining trend re-emerged and worsened with phase 3. Regional accessibility seems to have been more resilient. Excluding the sharp 2024–2025 drop, regional accessibility improved over the decade, leaving a net gain relative to 2016. However, phases 2 and 3 of the Basisbereikbaarheid policy did not contribute to that improvement. Phase 2's gains were effectively reversed after the implementation of phase 3, so the gains observed between 2016 and 2025 mainly reflected the original increase in regional accessibility between 2016 and 2023.

Spatially, rural western Flanders and central Limburg benefited most over the decade, whereas the Metropolitan Core Area (MCA) and its surroundings saw notable losses. Additionally, the results show that lower-density regions are not uniformly worse off on average, but they do exhibit greater variability, including larger rises and drops. This reflects the fragility of rural public transport networks where small adjustments can have outsized effects. While the density-based summary offers a first look at the distributional patterns of accessibility, a more nuanced equity analysis would be needed to assess impacts across socioeconomic groups.

#### 4.3.2 The influence of public transport alterations on accessibility

The second research question asks *how changes in service frequency, route configurations, stop locations and timetables across each phase of the Basisbereikbaarheid rollout (2023–2025) and cumulatively between 2016 and 2025 have driven the observed shifts in public transport accessibility*. This is addressed by using two case studies that examine nearby

routes and frequency changes in detail, decompose average travel times by mode, and track how travel times fluctuate across the day and week. Because detailed, phase-by-phase documentation of the implemented network changes was unavailable (Rekenhof, 2024), results could not be compared against an exhaustive list of alterations.

From 2016 to 2023, both areas saw more transit lines, mostly short-distance buses that marginally expanded coverage. But overall, accessibility outcomes were mixed, with many hexagons registering declines. In both cases, regional (museum) accessibility generally mirrored local (school) trends but with milder losses, likely because longer trips diluted the impact of changes to any single line.

Phase 2's network simplification and reinforcement of core lines are visible in both cases. In Morkhoven, minor lines and stops were cut while frequencies on the central corridor increased, yielding higher accessibility despite slightly longer walks. In Pelt, stop removals and line consolidations produced steadier, but not uniformly positive results. Given the absence of detailed change logs and the aggregation nature of the modal-time calculations, some counterintuitive outcomes (e.g., declining walk times despite fewer operating stops) cannot be fully explained.

The 2024–2025 period introduced further anomalies. In Pelt, regional accessibility declined even as total travel times fell. The removal of a small northern line depresses accessibility in adjacent hexagons, underscoring how minor lines can be pivotal in rural settings. In Morkhoven, roadworks forced detours away from the central bus axis, wiping out previous gains and sharply increasing walking times. This underscores the vulnerability of single-axis rural networks compared to semi-rural nodes like Pelt, where multiple higher-frequency lines offer greater robustness.

Combining an accessibility metric with modal components and time-of-day profiles yields a richer picture of when and how network adjustments affect mobility, but it has many drawbacks. Focusing on the home side of networks omits segments near the opportunity locations. Additionally, the inclusion of nearly all reachable opportunities does not necessarily reflect realistic destination choices. Moreover, to improve year-to-year and cross-hexagon comparability, the number of opportunities was fixed when estimating modal and average travel times, but this introduced gaps when trips exceeded the time budget. Lastly, museums that were only sporadically reached were filtered out before the detailed analysis. These factors likely contributed to the anomalies noted in both case studies. While the approach offers useful additional insight, such as estimating the average walking, waiting and in-vehicle times, and how travel times differ throughout the day, its practical value is hard to judge when results show conflicting information (e.g. the discrepancy in Pelt). The

core problem is that I tried to reconcile a potential-based approach, with the aim of disentangling travel time components. The cumulative nature of gravity measures means that, for example, the average walking time for one hexagon is comprised of the walking times of numerous trips. Each additional trip included in the average makes it harder to understand why the average shifts in a certain direction. A potential remedy could be to rerun the modal/time-of-day analysis with a limited set of opportunities (e.g., the X closest) or to visualise accessibility values rather than travel times.

While extrapolating the findings beyond the case studies is difficult, several takeaways stand out. Firstly, even modest frequency increases can yield meaningful gains in rural contexts. Additionally, major restructurings that prioritise main corridors and remove small routes risk disenfranchising rural users unless substitutions (e.g., frequency boosts on nearby lines) are provided. Changes to a single main line on which rural populations rely can swing accessibility sharply in either direction, as seen in the Morkhoven case. Removing stops on main lines only slightly raises walking times, which is potentially offset by decreased bus times. Finally, temporal sensitivity varies with scale and with the availability of transport options: networks with more alternatives exhibit smoother time-of-day profiles than those reliant on a single corridor.

## 4.4 Detours and delays: Challenges and limitations

Before discussing the potential directions for future research, it is useful to first discuss all the delays and detours that occurred throughout this research journey. Apart from limitations on the results, which have been discussed in the previous section, there are three main categories in which the limitations and challenges of this study can be subdivided: limitations on the data and limitations on the methodology.

### 4.4.1 Limitations on the data

Regarding the data, a lot of issues can be pointed out. Starting with the data on the opportunities, secondary school data came from two sources: Flanders and Wallonia, to capture both Dutch- and French-language education in the BCR (Fédération Wallonie-Bruxelles, 2025; Vlaams Ministerie van Onderwijs en Vorming, 2024). Consequently, datasets differed in structure, requiring source-specific cleaning, which included filtering duplicates and removing school locations that only encompassed the first two years of secondary education. Other constraints were the omission of language preferences, school quality, or school types in the model; all schools are treated equally.

The museum locations were drawn from OSM and required minimal cleaning. As with schools, all museums are treated equally; the data do not differentiate between frequently

visited venues in cities or small local museums. This can slightly influence accessibility at locations with many minor museums, though the concentration of museums in cities remains the dominant driver of accessibility. For consistency across years, the number of opportunities is held stable, as the study assumes the number of schools and museums is constant between 2016-2025.

Gridded 100m population estimates obtained from WorldPop (Bondarenko, M. et al., 2020a) support the accessibility summaries and per-mode travel-time changes. Two limitations are present. Firstly, there is a noticeable over-allocation of people to industrial zones (e.g., the ports of Ghent and Antwerp and the Antwerp–Limburg industrial corridor). Secondly, a static population layer for 2020 is used for all years due to limited temporal data availability; consequently, demographic changes are not captured.

Walking routes to stops were computed with r5r using an OSM road network snapshot from November 2024 (BBBike, 2024). To keep results comparable across years, the same 2024 OSM network was applied to all study dates (2016, 2023, 2024, 2025). This choice does not affect in-vehicle times as r5r derives those solely from GTFS data, but it does affect walking times. By consistently using the 2024 data, I effectively assume that walkable infrastructure remained relatively unchanged over the past decade, which is quite unlikely.

The final data aspect to discuss is the GTFS data. The data for 2023, 2024 and 2025 are obtained from Professor Poorthuis' research group, while the data for 2016 was obtained from OpenMobilityData, (2024). Data from the research group had been prepared beforehand, while the 2016 data had not. However, no major inconsistencies with the 2016 data were discovered, and the accessibility maps did not yield any suspicious results. What is not included in the GTFS data and calculated accessibility are the on-demand services of De Lijn (earlier: 'belbus', now: flex transit). For on-demand services, no GTFS data exists, so they can only be included by using real-time data.

#### 4.4.2 Limitations on the methodology

The second category, closely related to the discussion of the results, focuses on the methodology and its limitations. Starting with the gravity measure approach, while its benefits and drawbacks and its comparison to other measures have already been extensively described in the methodology section, some remarks can still be made. While the gravity approach captures small network changes well, it produces abstract values that lack intuitive absolute interpretation. This makes it harder to define what a "good/bad" value is for accessibility, hampering its use for policy assessment, especially if the policy has no clearly defined quantitative targets.

Related to the gravity measure is the impedance function used. While the impedance function based on Martínez' & Viegas' (2013) research is easy to calculate and seems to provide nice results, but it has only been applied to small travel times, as used in Verachtert et al. (2023). However, the travel times used here are multiple times the travel times used by Martínez & Viegas (2013) and Verachtert et al. (2023). Consequently, it remains unclear whether the used travel time function is a good fit for this study. Another limitation is the assumption that the dimensions of 'far' and 'near' travel times show the same dynamic between secondary schools to museums. A necessary assumption, as only an average travel time to museums was available (DSP-groep, 2011) for this study. Additionally, it is not clear when something is 'far' or 'near'. A 10- and 90-percentile were used to estimate this, as it most closely aligns with research by Martínez & Viegas (2013) and Verachtert et al. (2023), however many more options exist. Nevertheless, the results produced by the impedance function and gravity measure do nicely align with the expected patterns.

Apart from all the measure-related limitations, there are some other drawbacks that often occur during accessibility calculations. First of all, there is the presence of edge effects. Using only opportunities located in Flanders and Brussels resulted in hexagons near the border not being able to access opportunities across the border, as they are not included in the analysis. For secondary schools, not including cross-border school locations might be a valid option as most students living in Flanders and the BCR most likely go to school in there. For museums, this dynamic might be slightly different, as people are probably more likely to visit museums in different regions.

Another bias that often returns in accessibility calculations is the Modifiable Areal Unit Problem (MAUP), which refers to a set of statistical biases that observe how results vary between identical analyses at different spatial scales (Levinson & King, 2020). To avoid this as much as possible, hexagons were used instead of statistical sectors, as their shapes are significantly more consistent. However, the hexagon's centroids were used for the accessibility calculations, and they had to be snapped to the road network, so there might be some degree of variation in spacing between hexagon centroids. A second precaution that was used to reduce the effects of the MAUP is the usage of small hexagons ( $\sim 0.74\text{km}^2$ ), so opportunities remained disaggregated. While the MAUP was not tested, the results seemed to provide nicely disaggregated results at the scale of Flanders and BCR. For more detailed analyses (such as the case studies), smaller hexagons might be necessary.

Similar to the MAUP, the Modifiable Temporal Unit Problem (MTUP) refers to how results differ as a result of using different temporal schemes (Farber et al., 2014; Levinson & King, 2020; Stępnia et al., 2019). To deal with this bias, large travel time windows of departure times with a 5-minute interval were used and tailored to the observed type of opportunity.

This included evening (returning from an opportunity) and weekend travel, where necessary, both of which are not often discussed in scientific literature. Additionally, large maximum travel times were set for which the impedance functions neared a value of zero, so all relevant opportunities could definitely be reached. While these implementations likely limited the MTUP biases, a broader time window might have provided better results. Especially since museums and secondary schools are used as proxies for regional and local accessibility, but their time windows still reflect the opportunity type, rather than the spatial scale they represent.

Lastly, some final considerations have to be made regarding the settings applied to the routing engine. A maximum walking speed of 4.5 km/h was used, similar to studies by Levinson & King (2020) and Verachtert et al. (2023). However, this does not represent less mobile people, such as the elderly, whose effective walking speed might be lower. Similarly, a maximum walking time of 30 minutes was used, which is significantly longer compared to the 400m or 800m distances used in other research (El-Geneidy et al., 2010; Hess, 2009), though other but similar distances exist as well (Chapleau & Morency, 2005; Mavoa et al., 2012). Nevertheless, those researchers often focused solely on public transit accessibility in cities.

## 4.5 Possible transfers: Directions for future research

Even though there are quite a few delays and detours in this research journey, there are still plenty of opportunities for a possible transfer to other research directions. Building upon the findings, limitations, and methodological considerations presented throughout this research, several avenues for future research are outlined below.

Firstly, Future research would significantly benefit from addressing the identified data limitations. For instance, cross-border opportunities could be included in future research, e.g. secondary schools or museums located outside Flanders and the BCR to reduce edge effects and MAUP-related biases. However, in that case, it is important to assess how often cross-border travel occurs and for which reasons, as it might not always be in the interest of people living along the border to go to an amenity across the border. For example, it is rather unlikely that Dutch-speaking people will go to Francophone schools across the border. Related to this, intra-opportunity differentiation could also be explored in the future. Additional characteristics of opportunities (e.g., museum popularity, educational specialisation, language preference) could be included to more accurately reflect real-world attractiveness (Handy & Niemeier, 1997; Siddiq & Taylor, 2021). While an interesting avenue to explore, the data needed to accomplish this might not exist, and it would also make the measure harder to understand. Another data-related path that can be explored is

the inclusion of multiple types of opportunities, especially when using them as a proxy for, e.g. regional or local accessibility. This is in line with research by Verachtert et al. (2023), who combined multiple destinations as a proxy for different spatial scales of accessibility. A drawback, however, is that there is no delineation of how much each opportunity should contribute to accessibility relative to other opportunities.

Two other avenues of future research can be explored. Firstly, the inclusion of GTFS data covering end-2022 to explicitly evaluate the impacts of phases 0 and 1 of the Basisbereikbaarheid policy. Additionally, historic OSM datasets on the road network could also be used to account for changes in the walking network. Several other methodological improvements could also strengthen the analysis and broaden its applicability. First of all, you could aim to integrate on-demand transit services (flex transit, belbus) into the theoretical accessibility calculations to capture the on-demand aspect of accessibility. Additionally, you could even aim to repeat this study, but using real-time GTFS data instead of the planned GTFS data. In doing so, the accessibility values calculated in this study could serve as a baseline to which the real-time accessibility can be compared. This would allow us to assess the impact of delays, cancellations, actual arrival/departure times and strikes and could offer results of great interest to transit planners (Liu et al., 2023). The measure constructed in this research could also be tested for its robustness. Systematically testing the sensitivity and robustness of the used gravity measure and impedance functions would ensure their reliability across different spatial scales and times of the day. Additionally, future studies could experiment more with different settings for the current impedance function or with alternative impedance functions altogether. Another way to further this accessibility study could be by including a utility function to better represent user behaviour and preferences.

As hinted towards earlier, different spatial and temporal settings of the measure could also be studied. While the current hexagon size is sufficient for a Flanders-wide analysis, utilising smaller hexagons might be more beneficial when assessing case studies in detail or focusing on city environments, reducing MAUP effects. Additionally, implementing broader time windows to capture public transport services across vaster periods might also provide a more holistic view on accessibility, especially when the goal is to assess accessibility at different spatial scales (e.g. regional, local). Within regard to focusing on accessibility at different spatial scales, further analyses can be conducted by comparing these different spatial scales and clarifying their (dis)similarities. On the other hand, focus could also be put on better understanding rural(-urban) dynamics of public transportation. While public transit research often focuses on the urban environments, rural areas are also important to

consider (Delbosc & Currie, 2011; Gössling, 2016), especially given their often less robust public transit situation.

To better understand the changes in accessibility for different socioeconomic groups, further research is also needed. An expanded focus on different socioeconomic groups by incorporating demographic factors such as income, car ownership and age can offer valuable insights into how the altered public transit network affected different socioeconomic groups. Specifically, a detailed accessibility analysis could also be conducted on people with varying levels of mobility (e.g., elderly, less mobile populations) by adjusting walking speeds and maximum walking times. This could be especially interesting given the removal of numerous stops during the implementation of the new policy.

Lastly, future research could also focus on the relation between accessibility studies and policy and public transit planning, enhancing the link between policy, planning and scientific research. A first suggestion for future research is comparing the measure used here with the tools used by public transit planners to assess accessibility changes. In theory, the measure used here could be used in ex ante evaluations of potential public transit changes to estimate their impact, although it might be cumbersome if a lot of scenarios for different POIs have to be tested. Additionally, it would be ideal if research outcomes could directly be compared with stated policy goals, providing insights into the effectiveness of public transport changes. While this sounds nice on paper, policy goals will likely be difficult to compare with calculated accessibility values.

This also brings us to the question: are the calculated changes in accessibility similar to the changes people experience, and how can we examine this? To understand this, it is critical to first understand the drivers of accessibility change. For instance, research can be conducted focusing explicitly on identifying causal mechanisms behind observed accessibility changes, such as route alterations, frequency modifications, infrastructure disruptions, or timetable adjustments. However, to ensure scientific research that can be useful to transit planners and policy makers, it is vital to collaborate closely with each other to pinpoint critical criteria and areas requiring deeper insight. To this end, the following question is very important: what information do transit planners need from scientific research to facilitate their operations? This is, in my opinion, also the most significant drawback of this study: not cooperating with policy makers or public transit planners. The findings of this study are certainly interesting and provide some valuable insights into accessibility and its changes over the years. However, since no cooperation existed with other researchers, transit planners or policy makers, the question remains whether this study is useful for future research, transit planners or policy makers.

## 5 Conclusion: The study's final stop

This study used a gravity measure to analyse spatiotemporal changes in public transport accessibility to secondary schools at the local and regional scale across Flanders and the BCR (Brussels-Capital Region) between 2016 and 2025. Two central research questions guided this study: first, *how and to what extent did local accessibility to secondary schools and regional accessibility to museums evolve across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025, and how do these trajectories differ between high-density and low-density areas?* Second, *how have changes in service frequency, route configurations, stop locations and timetables across each phase of the Basisbereikbaarheid rollout (2023-2025) and cumulatively between 2016 and 2025 driven the observed shifts in public transport accessibility?*

This study revealed a nuanced landscape of accessibility gains and losses. Between 2016 and 2025, accessibility to secondary schools declined by approximately 8% on average, with most decreases observed in and around the MCA. Regional accessibility to museums, on the other hand, remained largely stable or improved marginally. The implementation of phases 2 and 3 of the Basisbereikbaarheid policy played a major role in the 2016-2025 accessibility change. Regarding phase 2, contrary to widespread public concern (VRT NWS, 2024a, 2024d) three quarters of people experienced only limited change or obtained slightly improved accessibility. Phase 3 (January 2025), on the contrary, saw declines across nearly the entire area, with 70%-80% of the population experiencing some form of decline. Additionally, the magnitude of decline in phase 3 outweighed the gains made in phase 2, meaning that, based on these two phases, the new Basisbereikbaarheid policy did not improve accessibility. The effects of phases 0 and 1 could not be assessed separately, thus, their influence on accessibility change remains unknown. While the 2016-2025 average decline in accessibility only amounted to a couple of per cent, it is important to note that the low-density zones experienced more extreme accessibility swings, both positively and negatively. This underscores how marginal network tweaks can disproportionately affect areas with sparser service, while high-density regions showed more muted response patterns due to their more robust public transit services.

The two rural case studies further illustrated the earlier findings. Both in Morkhoven and Pelt, minor lines and a significant number of stops were removed because of the efficiency-related changes of phases 2 and 3 of the new policy. In some instances, this was counterbalanced by increased frequencies on main routes, but overall accessibility tended to decline. While this type of case study analysis provides useful contextual information regarding the time of day at which accessibility changes occur, and which modes are most

affected, its findings are hard to extrapolate. Noteworthy observations are that even modest frequency increases can yield meaningful gains in rural contexts. Additionally, major restructurings that prioritise main corridors and remove small routes risk disenfranchising rural users unless substitutions (e.g., frequency boosts on nearby lines) are provided. Lastly, changes to a single main line on which rural populations rely can swing accessibility sharply in either direction, as seen in the Morkhoven case. The case studies clearly illustrate the potential difficulties of altering the public transit network in rural areas.

Despite these insights, several limitations remain. The lack of GTFS data between late 2022 and the end of 2023 inhibited a clean separation of the effects of phases 0 and 1 from earlier changes between 2016 and 2022. Additionally, this study omitted cross-border service interactions, introducing edge-effect biases. On-demand services (belbus and flex transit) were also excluded, and the reliance on gravity-based “effective opportunities” metrics, while valuable for comparative purposes, limits interpretability. Moreover, while high-resolution uniform hexagons were used, some degree of MAUP-related bias might still persist due to the non-uniformity of the hexagon centroids and the relatively low resolution of hexagons at the case study area scale. Additionally, MTUP distortions, while limited, might also be present as distinct timeframes were used for the accessibility calculations.

Looking ahead, future work could incorporate dynamic, on-demand service modes and real-time data streams to capture the full nature of the transit networks as well as external factors such as delays, strikes and last-minute changes. Additionally, ample changes can be made to the data used, for instance, including additional opportunities, using GTFS data to encompass phases 0 and 1 of the new policy and using additional socioeconomic information. Engaging directly with stakeholders as transit planners or policy makers could tie scientific research and planning and policy needs closer together.

In conclusion, this study assesses the impact of the large-scale overhaul to the public transit network that is the Basisbereikbaarheid decree, while simultaneously trying to understand how alterations in service frequency, route configurations, stop locations, and timetables influence accessibility. The lack of contextual data on precise policy goals, public transit network changes, finances, material, personnel and so on hampers a full evaluation of the goal of the Basisbereikbaarheid policy of envisioning an equitable and efficient public transport system (Vlaamse Overheid, 2025). Necessary to achieve this, apart from an altered view on mobility, is continuous monetary support from the government and in-depth planning and coordination with stakeholders (Hensher et al., 2015; Sohail et al., 2006).

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